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INVESTIGATION OF TOXIC PROPERTIES OF MATERIALS USED IN SPACE VEHICLES

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FOREWORD

This study was initiated by the Toxic Hazards Branch, Physiology Division, Biomedical Laboratory, 6570th Aerospace Medical Research Laboratories. The research was conducted by the Missile and Space Division of the General Electric Company, Philadelphia, Pennsylvania, under Contract No. AF 33(657)-8029. The principal investigators for the General Electric Company, under the project leadership of Mr. William J. Olewinski, were Mr. Gordon Rapier, Dr. Tadeusz Slaweki, and Mr. Harold Warner. Capt. Alan B. Cooper, USAF, MC, and Dr. N.A. Poulos, task engineers, were the contract monitors for the Biomedical Laboratory. The work was performed in support of Project No. 6302, "Toxic Hazards of Propellants and Materials," Task No. 630203, "Identification of Toxic Materials." This study was started in March 1962 and completed in January 1963.

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ABSTRACT

The objectives of this program were: (1) to compile lists of materials presently used or proposed for use in spacecraft — specifically, the Apollo, Mercury, Gemini, and Dyna-Soar programs—and to assess the possible toxic properties and breakdown products of these materials under thermal and other anticipated stresses and (2) to evaluate methods for the detection and identification of space cabin contaminants for the purpose of compiling the requirements, methods, and specifications on available instrumentation. These in turn can serve as the basis for development of a compact kit for detection of toxic off-gassing from materials employed in space vehicles.

For other than short duration missions, monitoring instrumentation must be capable of the detection and identification of a wide variety of toxic contaminants, some of which may not have been anticipated. A highly sensitive multiple gas detector, either directly or in combination with a trace gas separation and concentration technique, appears to be a desirable approach. Many of the comments on gases and vapors also apply to particulate type contaminants.

PUBLICATION REVIEW

This technical documentary report is approved.

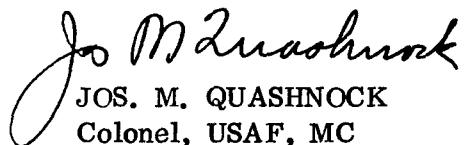

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INTRODUCTION

In a spacecraft with a closed and recirculated atmospheric environment, gradual contamination of the environment by the accumulation of toxic gases, vapors and dust particles may be expected under normal operating conditions unless suitable control equipment is provided. This contaminant build-up problem is particularly complex for long duration manned space missions.

In order to establish an atmosphere control regime, it is essential to identify those materials projected for use in spacecraft which are potentially capable of evolving toxic substances; to learn more about the characteristics of these evolved toxic substances; to devise methods of eliminating or reducing the accumulation of these substances to prescribed safe levels in closed environments; and to detect whether in fact prescribed safe levels are being violated.

Listed below are several methods envisioned for control of toxic contaminants in spacecraft atmospheres:

- Employment of devices for removal of the contaminants per se as they evolve.
- Construction of spacecraft using materials which are not toxic per se and which do not outgas toxic contaminants.
- Limitation of the total amount of potentially toxic materials used in spacecraft construction, i. e., permit contamination within safe limits.

No doubt, for the present and immediate future, all three methods will be employed. But it is obvious that to insure the reliability of these methods, there is an urgent requirement to obtain more information regarding the materials planned for use in spacecraft as well as knowledge regarding the toxic properties of these materials and instrumentation for their detection.

Thus the objectives of this study were twofold and subdivided into two phases. In Phase I, the objective was to determine as many materials as possible which were being used or considered for use in spacecraft construction and to delineate the outgassing and/or other decomposition products under expected environmental conditions. Having appraised the contaminants which might evolve from the various materials, the Phase II objective was to compile methods for the detection and identification of these contaminants as a basis for the development of a compact toxic instrumentation kit for spacecraft applications. It should be noted that a well designed manned spacecraft will have equipment on-board to control the concentration of atmosphere contaminants. This of course does not preclude a build-up of contaminants due either to partial or total failure of this equipment or the evolution of an unexpected toxic constituent which the equipment cannot control. Thus, the requirements, methods and specifications for suitable instrumentation must proceed on the basis of potential contaminants based on planned spacecraft materials without regard to the efficiency of the contaminant removal equipment.

SOURCES OF CONTAMINANTS

The contaminants which may accumulate in the atmosphere of a manned spacecraft are derived from two principal sources: (a) biological and (b) materials and equipment.

Since there is information presently available pertaining to the toxicity of the various substances derived from human metabolic and waste products, it was decided only to summarize these substances and to concentrate the Phase I efforts on evaluations of material derived substances.

BIOLOGICALLY DERIVED CONTAMINANTS

Most substances which are evolved by man and animals as products of their metabolism are predictable. Table 1 summarizes the substances which have been reported. These are expected to vary appreciably, depending on vehicle type, length of mission, and contaminant disposal techniques employed. The rates of output may vary considerably as a function of such factors as diet, temperature and pressure. Although the list seems impressive, perhaps only a relatively small number of human waste products appearing in Table 1 demand serious consideration. Those that are considered toxic under normal conditions and evolve from feces and flatus as well as from urine are indicated in Table 2. The selection criteria, Table 3, was based on the classification proposed by Hodge and Sterner (Ref. 1).

MATERIAL DERIVED CONTAMINANTS

Materials used in spacecraft construction present the other prime source of potential toxic substances. A wide variety of materials (metals, plastics, rubber, finishes, adhesives, etc.) have been used and are anticipated for use in manned spacecraft.

Metals

In general, because of their high vaporization temperatures, metals are considered to be relatively non-toxic except when contained in the spacecraft in the form of dust or vapor. Table 4, based on data in Appendixes A through C and G.E. manned space vehicle studies, lists the metals expected to be found within a typical spacecraft. These metals, generally found in combination with each other, or as oxides, can be considered as the basic materials from which the structure and equipment will be manufactured.

These metals, with the exceptions noted in Table 4, are considered to present no toxic hazard for use in a spacecraft environment. They generally have vaporization temperatures well above expected ambient atmosphere temperatures. Oxidation of these materials appears to pose no problem since the oxides are particularly stable and will not outgas in the temperature/pressure environment expected.

Plastics

Plastic compounds of various types will be found in manned spacecraft. These materials, fiberglass, phenolics, plexiglas, styrofoam and teflon, will be used as trim,

TABLE 1
HUMAN WASTE PRODUCTS (1)

Feces and Flatus

Indole	Methyl mercaptan	Amino acids
Skatole	Nitrogen	Ammonia
Paracresol	Hydrogen	Mucus
propionic acid	Proteoses	Starch granules
Hydrogen sulfide	Peptones	Fats and fatty
Methane	Peptides	acid

Urine

Water
Solids
Inorganic Salts
 Cations - Sodium, potassium, calcium, magnesium, ammonium
 Anions - Chloride, phosphate, sulfate, carbonate
Organic Compounds - Urea, uric acid, hippuric acid, creatinine, indican, oxalic acid, allantoin, purine bases, phenols, organic sulfates
Inorganic Compounds - Inorganic sulfates, sulfur dioxide

Expired Air

Oxygen	Isoprene	Furan
Carbon Dioxide	Methanol	Propionaldehyde
Water Vapor	Ethanol	Dimethyl sulfide
Acetone	Methyl furan	Isovaleraldehyde
Acetaldehyde	Carbon monoxide(2)	

Sweat

Inorganic Salts
 Cations - Sodium, potassium, calcium, magnesium, copper
 manganese, iron
 Anions - Chloride, sulfate
Organic Compounds - Lactic acid, glucose, urea, uric acid, ammonia, creatinine, amino acids, phenol, histamine, fatty acid esters.

(1) Condensed from Ref. 2 through 5.

(2) R. E. Forster, Per. Comm., Univ. of Penna., 1963.

TABLE 2*

TOXIC GASES AND VAPORS: HUMAN WASTE PRODUCTS

Substance	MAC in ppm
<u>Feces & Flatus**</u>	
Ammonia	100
Carbon Dioxide	5,000
Hydrogen Sulfide	20
Methyl Mercaptan	50
<u>Urine</u>	
Acetone	400 - 1,000
Phenols	5
Sulfur Dioxide	5 - 10
<u>Expired Air</u>	
Acetaldehyde	200
Carbon Dioxide	5,000
Ethyl Alcohol	1,000
Methyl Alcohol	200
Carbon Monoxide	100
<u>Sweat</u>	
Ammonia	100

*Condensed from Table 1 - those compounds with MAC's under 10,000.

**Skatole, indole, paracresol and proprionic acid are toxic although not listed in the TLV tables.

TABLE 3

TOXICITY CLASSIFICATION

Toxicity	MAC in ppm
Extremely toxic	10
Highly toxic	10 - 100
Moderately toxic	10 - 1,000
Slightly toxic	1,000 - 10,000
Practically non-toxic	10,000 - 100,000
Relatively harmless	> 100,000

TABLE 4
EXPECTED METALLIC SPACECRAFT MATERIALS

<u>Metal</u>	<u>Threshold Limit Value*</u> <u>Mg./M³</u>	
Aluminum	--	→
Antimony**	0.5	
Beryllium**	0.002	
Cadmium**	0.1	(as oxide)
Chromium**	0.1	(as CrO ₃)
Copper**	--	(Salts are known to be toxic)
Gold	--	
Iron	--	
Lead**	0.2	
Magnesium**	15.0	(as oxide)
Manganese**	5.0	
Mercury**	0.1	
Molybdenum**	5.0	(Soluble compounds)
Molybdenum**	15.0	(Insoluble Compounds)
Nickel	--	
Selenium**	0.1	
Silver	--	
Tellurium**	0.1	
Titanium	--	
Zinc**	5.0	(As oxide)

*Threshold Limit Values for 1962. 24th Annual Meeting of the American Conference of Governmental Industrial Hygienists.

**Known to be toxic (Ref. 6)

insulation, instrument faces, light structure, ducting, controls, switches, seats, food containers, instrument panel faces, and electrical insulation.

The majority of the high molecular weight plastic compounds are inert and non-toxic. However, frequently some unreacted material is present which may outgas under certain conditions of temperature and pressure. In addition, plasticizers such as tricresyl phosphate and camphor are toxic and may be volatilized if the material is heated.

Rubber

Rubber will be used in the spacecraft in many forms as seals, insulation, padding, shock mounts, survival gear, elastic, control handles, etc.

Natural and synthetic rubbers are non-toxic at normal temperatures. Natural rubber latex, however, contains ammonia which is released when heated. Neoprene latex contains partly polymerized chloroprene which gives off a strong odor. Finished rubber contains fillers, plasticizers, accelerators, anti-oxidants, retarders, vulcanizing agents and pigments. While most of these are innocuous, some might require additional investigation for long term use in a closed environment.

Finishes

All finishes such as paint, varnishes, enamels and lacquers contain toxic solvents (benzene, naphtha). Materials in the precured state are also hazardous.

Adhesives

Cements most probably will be carried in the spacecraft for making minor repairs. These cements, made from plastic or rubber, contain volatile solvents such as naphtha and toluene which can result in a toxic hazard during use and curing. Here again, concentration will be important and must be investigated with respect to long term continuous exposure.

Natural Fibers

Natural fibers such as cotton, flax and wool have had a toxic effect when inhaled in quantity (Ref. 6). It would appear, however, that the fibers in the manufactured product would not cause any irritation.

Lubricants

Petroleum products such as those which would be used for lubricating rotating machinery, contain relatively high percentages of naphthenes and aromatic hydrocarbons. While these components require relatively high concentration before becoming dangerous, it is conceivable that the increase in volatility of the substance caused by heat or friction could, over a period of time, cause at least unpleasant odors and visible fumes. Hydraulic fluids are known to be volatile and contain toxic compounds. The high operating pressures of these fluids (1,000 to 3,000 psi) are such that even minute leaks could create a toxic hazard by aerosolization.

Refrigerants and Heat Transfer Fluids

These fluids, notably freon, ethylene glycol, and alcohol can be expected to create toxicity problems if released into the controlled environment.

Fire Extinguishants

Carbon dioxide is expected to be the principal agent utilized for extinguishing internal spacecraft fires; however, other agents such as foams, dry chemicals (for example, sodium bicarbonate) and vaporizing liquids such as halogenated hydrocarbons are also available. Virtually all of the presently available agents are potential hazards when introduced into a closed environment.

Table 5 (Ref. 7) lists various fire extinguishing compounds, with the approximate concentrations at which they are lethal after 15 minutes of exposure. Since many of these compounds have an anesthetic effect before becoming lethal, the Table also gives the exposure times that the two vapor conditions take to produce anesthesia.

Contaminant Generation

Mechanical, thermal, and other stresses applied to materials may produce gases, vapors, or airborne particulate matter. Smoke, dust and liquid droplets are examples of particulate matter. The following are the stresses or mechanisms which are considered as significant to the generation of contaminants in spacecraft. Note that the total quantity of contaminants generated may be limited by either the ambient environment as in evaporation and condensation or the amount of the material available as in thermal decomposition.

Elevated Temperatures

An increase in temperature, such as would accompany a short circuit or fire, would most certainly produce toxic fumes, gases and smoke from a number of organic and inorganic materials found within the spacecraft. Only general statements can be made regarding the thermal degradation products and decomposition temperatures of many of the materials, in particular the plastics where the pyrolytic products depend to a great extent upon the degree of polymerization and the cure and additives used. Many polymers undergo slow self-polymerization even at ambient temperatures, so that different decomposition temperatures may be obtained from various samples of the same polymer.

Evaporation

Low ambient pressures affect materials in two ways: by evaporation of the material or a volatile component of the material, and/or by removal of the layer of adsorbed gas on the surface of the material. Sublimation and evaporation of materials are enhanced by the absence of an atmosphere in that molecules leaving the surface of the material are not reflected by collisions back to the surface.

The evaporation rate of a pure material can be calculated from kinetic theory (Ref. 8) as follows:

TABLE 5

APPROXIMATE LETHAL CONCENTRATIONS OF VARIOUS FIRE
EXTINGUISHING AGENTS (REF. 7)
(15 Minute Exposure)

Agent	Natural Vapor		min**	Pyrolyzed Vapor*		
	mg/l	ppm		mg/l	ppm	min**
Bromotrifluoromethane	5075	800,000	1	86	14,000	10
Carbon tetrafluoride	3220	895,000	2	3220	895,000	2
Bromochlorodifluoroethane	2200	324,000	4	52	7,650	-
1,2-dibromotetrafluoroethane	1340	126,000	1.5	17	1,600	5
Carbon dioxide	1180	658,000	1	1200	658,000	.25
Perfluoromethylcyclohexane	1165	81,000	5	117	7,500	5
Ethyl bromide	660	148,000	5	75	16,500	5
Dibromodifluoromethane	470	54,000	1	16	1,850	3
Chlorobromomethane	340	65,000	1	20	4,000	10
1,2-dibromo-2-chlorotrifluoroethane	285	25,000	2	8	700	8
1,2-dibromo-1,1-difluoroethane	190	20,700	-	110	12,000	-
Carbon tetrachloride	180	28,000	-	2	300	-
Methyl bromide	23	5,900	-	60	9,600	-
Methyl iodide	22	3,800	-	350	60,500	-

*Pyrolyzed in iron tube at 800°C to simulate a typical fire condition.

**Anesthesia time.

$$G = \frac{P}{17.14} \sqrt{\frac{M}{T}}$$

where

G = evaporation rate, g/(cm²) (sec)

M = molecular weight

T = absolute temperature °K

P = vapor pressure, mm Hg at temperature T.

It is not expected that the rate of evaporation of most metals will be a significant problem if the temperature is below 300°F. However, cadmium, zinc and mercury will evaporate appreciably below this temperature. Magnesium would appear to be a marginal material at this temperature.

Plastics, on the other hand, are more complex than metals because they contain a variety of ingredients. Although the basic polymer of the plastic is not likely to have a high enough vapor pressure to cause significant loss of material, some of the other ingredients may. In particular, plasticizers used in many plastics have relatively high vapor pressures; however, loss of plasticizer from a plastic is dependent on the diffusion rate of the plasticizer to the surface, which may be slower than the evaporation rate of the pure material would indicate.

For a given material, the saturated vapor phase that is in equilibrium with the surface of the solid or liquid exerts a finite pressure; this pressure, possessed by all liquids and solids, is the vapor pressure of the material. Moreover, if a material is a mixture of several ingredients, each ingredient exerts its own finite vapor pressure. The ingredients of such a material would, therefore, be expected to diffuse and escape from the materials at different rates until such time that the vapor phase of each ingredient in the material is in equilibrium with the vapor of the same ingredient in the ambient atmosphere. This, of course, assumes that the total pressure of the atmosphere is greater than that of the vapor phase within the ingredient. If the vapor pressure were higher than the total pressure, a condition of boiling would be obtained if a liquid phase were present.

For total pressures of 5 to 7 psia as would be expected in a manned spacecraft atmosphere, the steady-state total concentration of a specific contaminant resulting from the outgassing of a particular material is independent of the quantity of material available, and depends only upon an equilibrium condition between the vapor phase of the contaminant in the material and that in the environment. Table 6 lists the vapor pressure at approximate ambient temperatures for various toxic substances together with a comparison of the corresponding concentration at maximum permissible ACGIH limits. Note that if the rate of generation is low or the spacecraft not leaktight (a normal condition), the concentrations noted for equilibrium conditions may never be reached.

Recondensation

As noted above, whenever the vapor pressure of a substance exceeds the partial pressure of that substance in its ambient, molecules escape from the material into the

TABLE 6
VAPOR PRESSURE OF TOXIC SUBSTANCES

<u>Substance</u>	<u>Formula</u>	<u>T(1)</u>	<u>Vapor Pressure(2)</u>	<u>TLV(3)</u>
Acetaldehyde	C ₂ H ₄ O	20.2	1,000,000	200.
Acetic Anhydride	C ₄ H ₆ O ₃	36.	13,200	5.
Acrolein	C ₃ H ₄	34.5	526,000	0.5
Allyl Alcohol	C ₃ H ₆ O	33.4	52,600	2.
Allyl Chloride	C ₃ H ₅ Cl	27.5	526,000	5.
Amyl Acetate	C ₇ H ₁₄ O ₂	35.2	13,200	200.
Aniline	C ₆ H ₇ N	34.8	1,300	5.
Benzyl Chloride	C ₇ H ₇ Cl	22.0	1,300	1.
Butyl Acetate	C ₆ H ₁₂ O ₂	25.5	26,300	200.
Butylamine	C ₄ H ₁₁ N	32.0	26,300	5.
Carbon Disulfide	CS ₂	28.0	526,000	20.
Carbon Tetrachloride	CCl ₄	23.0	132,000	10.
Chloroform	CHCl ₃	25.9	263,000	50.
Chloropicrin	CCl ₃ NO ₂	33.8	52,600	0.1
Chloroprene	C ₃ H ₅ Cl	37.0	1,000,000	25.
Cresol	C ₇ H ₈ O	38.2	1,300	5.
Cyclohexane	C ₆ H ₁₂	25.5	132,000	400.
Cyclohexanol	C ₆ H ₁₂ O	21.0	1,300	50.
Cyclohexanone	C ₆ H ₁₀ O	38.7	13,200	50.
o-Dichlorobenzene	C ₆ H ₄ Cl	20.0	1,300	50.
p-Dichlorobenzene	C ₆ H ₄ Cl	39.0	6,600	75.
1,1 Dichloroethane	C ₂ H ₄ Cl ₂	39.8	526,000	100.
1,2 Dichloroethane	C ₂ H ₄ Cl ₂	29.4	132,000	50.
1,2 Dichloroethylene	C ₂ H ₂ Cl ₂	41.0	526,000	200.
Dichloromonofluoro- methane	CCl ₂ F ₂	42.4	13,200	1,000.
Diethylamine	C ₄ H ₁₁ N	38.0	526,000	25.
Dimethylaniline	C ₈ H ₁₁ N	29.5	1,300	5.
Dioxane	C ₄ H ₈ O ₂	25.2	52,600	100.
Ethyl Acetate	C ₄ H ₈ O ₂	27.0	132,000	400.
Ethyl Acrylate	C ₅ H ₈ O ₂	26.0	52,600	25.
Ethyl Alcohol	C ₂ H ₆ O	34.9	132,000	1,000.
Ethylbenzene	C ₈ H ₁₀	25.9	13,200	200.
Ethyl Bromide	C ₂ H ₅ Br	21.0	526,000	200.
Ethyl Formate	C ₃ H ₆ O ₂	37.1	526,000	100.
Ethylene Chlorohydrin	C ₂ H ₅ ClO	30.3	13,200	5.
Ethylenediamine	C ₂ H ₈ N ₂	21.5	13,200	10.
Ethylene Dibromide	C ₂ H ₄ Br ₂	32.7	26,300	25.
Furfural Alcohol	C ₅ H ₆ O ₂	31.8	1,300	50.
Heptane	C ₇ H ₁₆	22.3	52,600	500.
Hexane	C ₆ H ₁₄	31.6	263,000	500.

(1) Temperature in °C.

(2) Vapor pressure in ppm (by volume) at temperature T and 760 mm Hg total pressure.

(3) ACGIH Threshold Limit Values for 1962 in ppm.

TABLE 6 (Cont'd)

Substance	Formula	T(1)	Vapor Pressure(2)	TLV(3)
Hexanone	C ₆ H ₁₂ O	38.8	13,200	100.
Hydrogen Cyanide	HCN	25.9	1,000,000	10.
Hydrogen Fluoride	HF	19.7	1,000,000	3.
Iodine	I ₂	38.7	1,300	0.1
Mesityl oxide	C ₆ H ₁₀ O	26.0	1,300	25.
Methyl Acetate	C ₃ H ₆ O ₂	24.0	263,000	200.
Methyl Acrylate	C ₄ H ₆ O ₂	28.0	132,000	10.
Methyl Alcohol	CH ₄ O	21.2	132,000	200.
Methylcyclohexane	C ₇ H ₁₄	22.0	52,600	500.
Methyl Formate	C ₂ H ₄ O ₂	32.0	1,000,000	100.
a-Methyl Styrene	C ₉ H ₁₀	47.1	13,200	100.
Methylene Chloride	CH ₂ Cl ₂	24.1	526,000	500.
Nitroethane	C ₂ H ₅ NO ₂	38.0	52,600	100.
Nitrogen Dioxide	NO ₂	21.0	1,000,000	5.
Nitromethane	CH ₃ NO ₂	27.5	52,600	100.
2-Nitropropane	CH ₃ CH ₂ NO ₂	28.2	26,300	25.
Octane	C ₈ H ₁₈	31.5	26,300	500.
Pentane	C ₅ H ₁₂	36.1	1,000,000	1,000.
Pentanone	C ₅ H ₁₀ O	39.8	52,600	200.
Phenol	C ₆ H ₆ O	40.1	1,300	5.
Phosphorus trichloride	PCl ₃	21.0	132,000	0.5
Propyl Acetate	C ₅ H ₁₀ O ₂	28.8	52,600	200.
Propyl Alcohol	C ₃ H ₈ O	25.3	26,300	400.
Propylene oxide	C ₃ H ₆ O	34.5	1,000,000	100.
Pyridine	C ₅ H ₅ N	24.8	26,300	5.
1,1,2,2, Tetrachloroethane	C ₂ H ₂ Cl ₄	33.0	1,300	5.
Toluene	C ₇ H ₈	31.8	52,600	200.
Trichloroethylene	C ₂ HCl ₃	31.4	132,000	100.
Xylene	C ₈ H ₁₀	32.1	13,200	200.

(1) Temperature in °C.

(2) Vapor pressure in ppm (by volume) at temperature T and 760 mm Hg total pressure.

(3) ACGIH Threshold Limit Values for 1962 in ppm.

ambient. As the vapor pressure is a function of the temperature, if a volatile material is heated, molecules can escape. However, if the temperature of the ambient is lower, then the molecules will recombine and become airborne particulate matter. In general, particles so produced are quite small with few larger than 0.1 microns in diameter.

An example of this mechanism is the production of many airborne particles during an electrical discharge (e.g., motor brushes, relay contacts opening), when the electrode material is evaporated and recondenses into minute particles. Many particles are also formed by this process during the smoking of cigarettes.

Mechanical Generation

This mechanism includes any action, either natural or man-made, by which particles are mechanically produced and distributed into the air, such as the rubbing and consequent abrasion of two surfaces (such as cloth on cloth, causing lint). The particles generated by this mechanism are physically torn from the parent material and dispersed into the air. Liquid sprays are also considered in this category. The particles so produced are generally sized from 0.1 to 100 microns.

In determining the ease of production, the mechanical properties of the material, such as crystal structure, density, and bonding forces, are important for the solids; viscosity and density are the more important factors for the liquids.

Conversion of Gases

The formation of particles from the chemical change of a gas brought about by oxidation has been demonstrated in the laboratory and in the free atmosphere. The importance of this mechanism has only recently been realized. By chemical change, gases in the air may form other compounds which tend to be solid or liquid under normal pressure and temperatures. This process occurs for example in the smogs of Los Angeles. An excellent example of this type of production is the conversion of SO_2 gas into SO_3 by reaction with ozone and the subsequent formation of H_2SO_4 droplets when water vapor reacts with SO_3 . By this process, very small droplets in the range from 10^{-7} to 5×10^{-7} cm in diameter are produced.

Radiation

In discussing radiation damage to materials, it is convenient to consider three broad material classifications: metals and alloys; organic materials such as polymers, greases, and paint vehicles; and inorganic materials such as glasses or ceramics.

Metals and Alloys. In general, metals and alloys are relatively resistant to radiation damage. For the most part, only fast neutrons are effective in producing any damage in metals. Electrons or beta particles, having low mass, do not transfer sufficient kinetic energy to induce damage and gamma radiation, and being effective only in producing ionization, do not affect metal properties.

Organic Materials. Organic materials are notably susceptible to radiation damage. Unlike metals, there is a definite molecular structure in organics which may be destroyed and is not capable of healing through processes akin to annealing. It has been shown repeatedly that radiation-induced damage is dependent on the total energy absorbed, and sometimes on the radiation intensity, but rarely, if ever, dependent on the type or source of radiation.

The types of damage produced in organics by irradiation are summarized as follows: Polymers may be produced by chain scission and subsequent interaction of active bond sites; graft polymers may be produced; long-chain polymers (rubber, polyethylene, etc.) may be cross-linked to form rigid three-dimensional networks; polymers may be degraded to reduce molecular weight, increase vapor pressure, decrease viscosity, and decrease mechanical strength. Crystallinity in polymers such as nylon, polyethylene and teflon is destroyed by radiation.

Inorganic Materials. Inorganic materials are generally resistant to radiation damage, as are metals. This is undoubtedly due to the nature of ionic rather than covalent bonding inherent in organic structures.

IRRADIATED MATERIALS EVALUATION

Although decomposition of materials to the point of changing their physical properties occurs at radiation doses many times higher than those lethal to man, outgassing of toxic gases may possibly take place at doses several orders of magnitude less. During long-term missions, such as space station or planetary probe operations, the spacecraft crew may take refuge in specially shielded chambers when high intensity, high energy, short-term radiation is imminent. Thus the normal spacecraft living quarters could easily be irradiated with doses high enough to cause toxic outgassing from materials.

Procedure

As previously noted, organic materials tend to have the least radiation resistance in terms of physical properties. Among the organics, the plastics and elastomers show a marked susceptibility to radiation. In general, plastics are more resistant to radiation damage than are elastomers. Plastics may be exposed to 10^4 to 10^8 roentgens irradiation before a physical change appears, while elastomers can only absorb dosages of up to 10^0 roentgens before being damaged, (Ref. 9). Bovey (Ref. 10) has shown that when subjected to high dosage radiation, some plastics (notably polymethyl methacrylate) will evolve H_2 , CH_4 , CO , CO_2 , O_2 and other hydrocarbons.

In general, irradiation effects studies have been concerned with performance degradation, reduction in mechanical or other properties, outgassing, etc., at high dose rates, i.e., limit conditions. No data was found concerning the effect of minimum of threshold dose rates. Therefore, it was concluded that an exploratory evaluation should be made of the effects of radiation on selected organic materials at dose rates considerably lower than those which had been reported in the literature. A dosage of 6,000 roentgens at a rate of 50 roentgens per minute was selected. This dosage is one order of magnitude higher than man's LD_{90} .

Table 7 lists the four materials together with helium and paraffin samples, which were evaluated as part of the study program. Since Kel-F is a fluorinated compound, its container was lined with a high-purity paraffin. A sample of paraffin alone was also included in order to evaluate, separately, the radiation effects on the paraffin. The sample container used is shown in Figure 1. This glass type container is used routinely for gas analysis at General Electric. The sample material is introduced into the sample volume through the seal-off tube. Examination of the larger glass tube affixed to the top of the sample volume will reveal a "break-off" seal approximately 20 percent of the distance up from the top of the sample volume. The sample volume is evacuated through the seal-off tube following introduction of the sample material. The volume is then recompressed to the desired pressure with the specified gas or gas mixture. While maintaining these conditions the seal-off tube is heated and pinched-off to effect a seal.

When it is desired to connect the sample volume into the analytical instrumentation complex, a thoroughly washed and cleansed steel plug is placed in the tube above the break-off seal. The entire container is connected to the instrumentation manifold by means of the 12-30 taper and the volume above the break-off seal evacuated. The steel slug is then lifted magnetically and allowed to fall, fracturing the break-off seal and thereby admitting the gas mixture, in the sample volume, into the instrumentation manifold.

The glass containers were prepared by a thorough cleaning with a solution of potassium dichromate and sulfuric acid followed by distilled water rinses and overnight oven drying. The sample materials were shredded, where necessary, and introduced into the sample volume through the seal-off tube. The container was filled to 7 psia (the expected total atmosphere pressure in a manned spacecraft) with an inert atmosphere of helium. Helium was used in these exploratory tests to preclude masking of the offgassing products by high oxygen and nitrogen partial pressure concentrations. It should be noted that the use of helium in these exploratory tests thus did not permit recombinations of some of the offgassed products with oxygen or nitrogen.

Gamma irradiation and subsequent gas analysis was accomplished at General Electric's 15,000 curie cobalt-60 facility in Schenectady, New York. Figure 2 is typical of the test set-up for the irradiation of the samples. The samples were arranged in a suitable rack at a specified distance from the radiation source. In the lower center of the picture is the ion chamber for measuring the radiation dose rate. Immediately after the irradiation, gas analyses were run on the samples using a GE high resolution (250 unity mass) mass spectrometer.

Results

In Table 7 are the data from the mass spectrometer analysis of the material samples selected. Data from both the control and irradiated samples are presented. Quantities given are in mol %, (percentage concentration). The total sample volume after expansion into the mass spectrometer was 250 cc. This volume, with the pressures as noted, and with the concentration levels indicated, can be used to compute approximately the actual quantity of gas generated.

TABLE 7. MASS SPECTROMETER ANALYSIS OF IRRADIATED SAMPLES (IN MOL %)

Gas	Helium		Hypalon-20		Silicone Rubber		Thiokol		Paraffin		Kel F	
	Control		Control	irradiated	Control	irradiated	Control	irradiated	irradiated	Control	irradiated	irradiated
Helium	99.9		97.3	96.9	99.9	99.9	99.4	99.4	99.9	99.1	99.3	
Water Vapor				0.01		0.01	0.05	0.2		0.01	0.01	
Methane						0.01						
Nitrogen	0.002		2.0	2.5		0.01	0.3	0.3	0.01	0.6	0.5	
Oxygen			0.4	0.5			0.1	0.1	0.05	0.2	0.09	
Argon			0.01	0.02			0.005			0.005	0.002	
Carbon Dioxide				0.01		0.04	0.04	0.03	0.001	0.001	0.007	
Sulfur Dioxide			0.2	0.003						0.0005		
Carbon Tetrachloride			0.1	0.05								
Ethylene							0.02					
Hydrocarbons									0.006	0.005	0.017	
Sample Pressure mm/250 cc	125		117	115	129	127	118	119	129	135	130	

Note: Helium irradiation and paraffin control were not considered necessary.

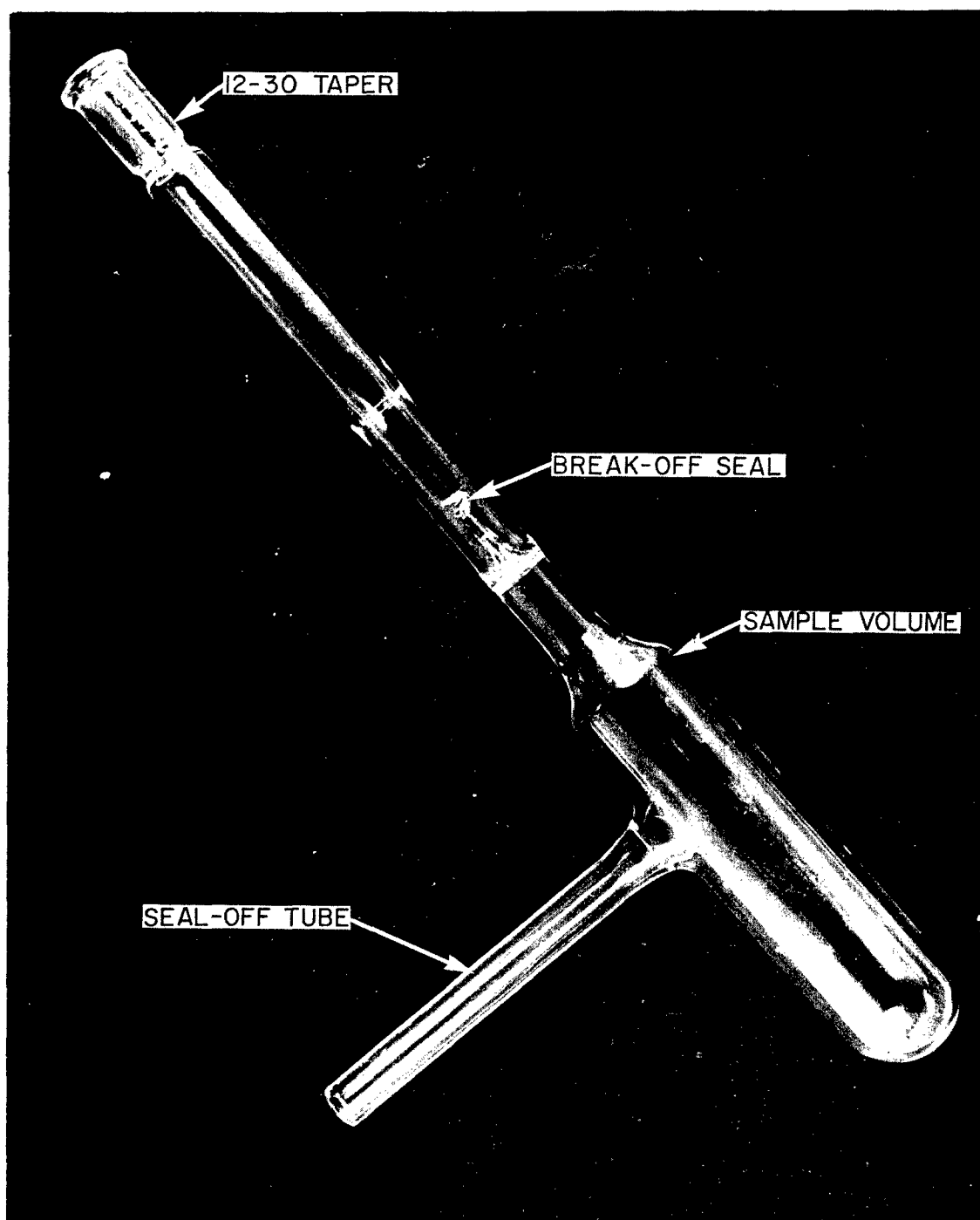


Figure 1. Sample Container

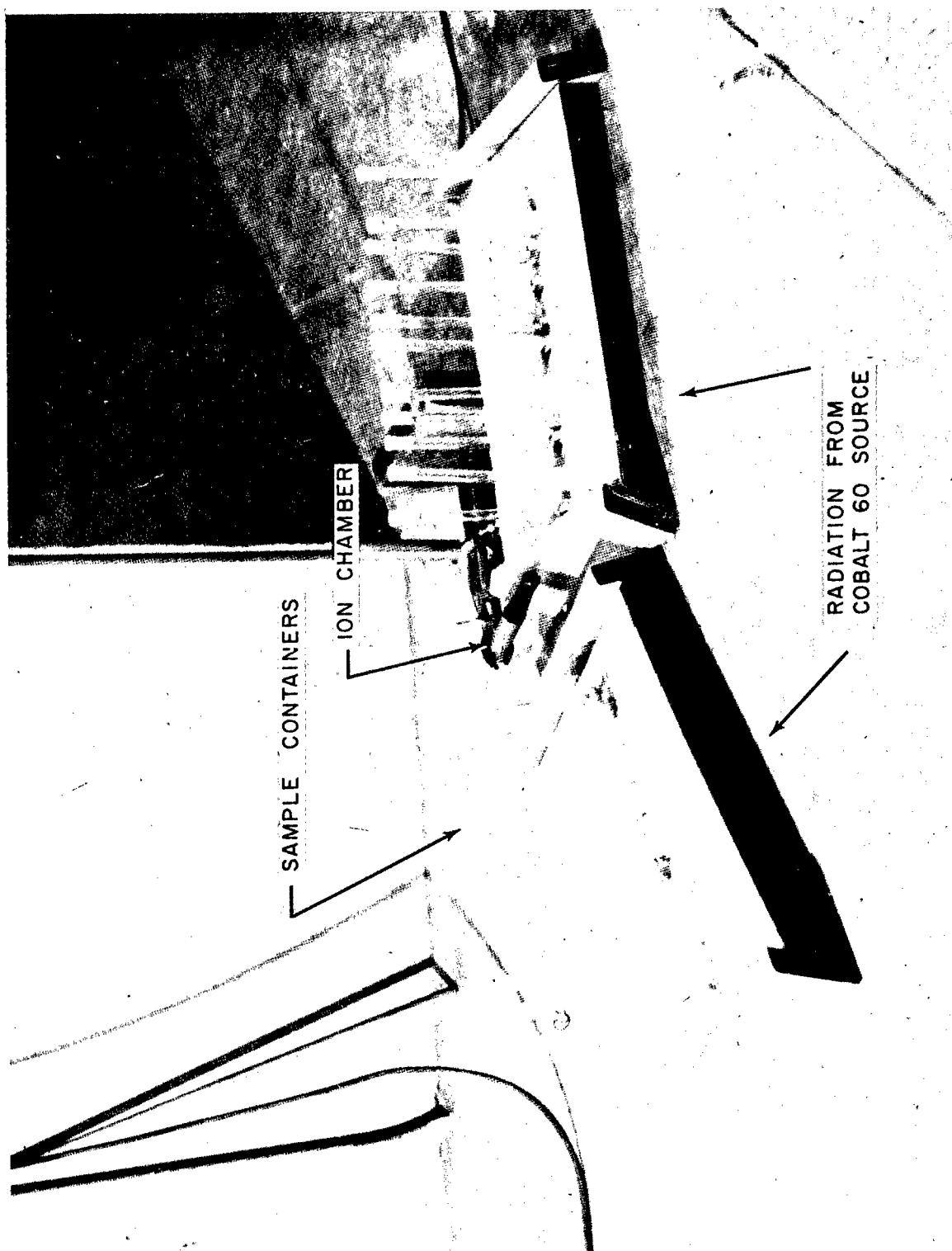


Figure 2. Typical Radiation Test Set-Up

Offgassing of significance, after irradiation, occurred in only two instances. One — carbon dioxide from Kel-F, 70 ppm — is of relatively little importance; the other — chlorinated hydrocarbons from Kel-F, 170 ppm — is of importance. Kel-F is employed as electrical insulating material under elevated thermal environments; MAC's among chlorinated hydrocarbons range as low as 25 ppm.

However, the volume of the sample container was about 60 ml, half of which was occupied by loosely packed sample materials either in powder form or as finely cut up pieces. Assuming a packing factor of 0.5, the total volume occupied by gas was about 37.5 ml. Assuming further the maximum dimensions of sample pieces to be 1 cm x 1/2 cm x 1/10 cm, 12.5 cc of sample has an approximate area of 325 sq. cms. Thus, a minimum of 325 sq. cm. of sample participates in the offgassing process into a volume of 37.5 cc, a condition much more severe by several orders of magnitude than would be encountered in the interior of a manned space vehicle.

From the foregoing paragraph, it might be assumed that off-gassing from irradiated materials is not a problem. However, it would be presumptuous to make this assumption without a full scale study, involving irradiation of many more materials, in both oxygen and nitrogen atmospheres.

THERMAL DEGRADATION

Materials proposed for use in spacecraft may be divided into two broad classes, metals and non-metals. From the point of view of thermal degradation, metals may be considered as inert under expected thermal environmental conditions for manned spacecraft and therefore may be omitted from further discussions.

Among the non-metals, few natural products such as latex, natural fibers, and leather are likely to find spacecraft applications. Other non-metallics such as ceramics, inorganic coatings, and glasses are well known for their inertness even at elevated temperatures and for this reason should not cause any concern. The main source of possible toxic contaminants are the various polymeric materials together with the additives, solvents, plasticizers and catalytic agents used in their manufacture.

The tentative materials for manned spacecraft, Appendices A, B, and C, contain large numbers of such polymers. Their use is quite varied — from structural members to potting compounds, electrical wire insulation, coatings, enamels, varnishes, items of clothing, utensils, and a host of other applications too numerous to mention.

Polymer Breakdown Mechanism

Degradation of such polymeric materials takes place continuously, even at ordinary temperatures. With temperature rise the degradation is accelerated. The mechanism of such degradation is quite varied and is also temperature dependent. At lower temperatures, loss of volatiles usually occurs first. This may be coupled with very slow additional cross-linking and perhaps some oxidation at or near the surfaces exposed to an oxidizing atmosphere such as air. This process is commonly referred to as aging. At low temperatures, most large polymer molecules are relatively stable. Thus during aging very little evolution of low-molecular weight gases may be expected to take place. Any gases evolved during aging are usually low boiling point solvents

and water vapor. The mechanism of gas evolution under such conditions is essentially that of diffusion of gases through solids and through any pores and gas pockets that may be present.

At higher temperatures, in addition to above processes, depolymerization of the polymers into the constituent monomers may also take place. Their evolution will depend primarily on their vapor pressure and to some extent on the diffusion.

At still higher temperatures the monomeric substances may undergo partial decomposition, chemical reactions may take place between such fragments and the parent polymer, the products of the condensation reactions may be evolved, and oxidation may take place at a much higher rate. Increasing the temperature still further, the polymer may break down in random fashion into larger molecular forms which may further decompose or react with each other to form a whole spectrum of chemical compounds.

At very high temperatures some polymers carbonize with almost complete loss of hydrogen and other groups. Other polymers decompose completely without leaving residues.

The exact mechanism of polymer breakdown depends primarily on the molecular structure (Ref. 12). For instance, the breakdown of simple vinyl polymers takes place in accordance with various mechanisms as follows:

- a. Breakdown of the chain into a molecular spectrum having from one to about 50 carbons. An example of such a polymer is polymethylene. After an initial step of degradation has taken place, resulting in the formation of some free radicals, the main process of degradation depends on a transfer of the free-radical activity through hydrogen abstraction.
- b. If some of the hydrogen in the polymer chain is replaced by some other atoms or radicals the displacement of hydrogen by intramolecular abstraction at the site of scission becomes more or less limited. As a result some scission reactions cause free radical formation which can unzip into monomers, can react further with the polymer or other radicals. In case of vinyl polymers the monomer yield is quite high. Table 8 (Ref. 12) lists the half-life (T_h) and monomer yields of a number of polymers pyrolyzed in a vacuum at temperatures below 600°C. Polystyrene, which is really a polymethylene in which one of the hydrogen atoms is replaced by a phenyl group, yields on pyrolysis below 600°C, 40% monomer.
- c. Breakdown by a mechanism yielding almost 100 percent monomer.

Polymers, in which one of the hydrogens on alternate carbons is substituted by a methyl radical and the other hydrogen by some other, still larger group such as phenyl or ester, decompose into free radicals which in turn unzip into monomers. This action is due to steric hindrance which prevents intramolecular hydrogen transfer by blocking of scission sites by these large groups. Methyl methacrylate and alpha - methyl styrene polymers belong to this category. These polymers when heated at temperatures to 500°C, decompose almost completely into monomers. In case of

polytetrafluoroethylene (Teflon), which also yields monomers on thermal decomposition, steric hindrance is not involved. The carbon-fluorine bond is much stronger than the carbon-hydrogen bond, the result of which is a chain scission into free radicals which unzip into monomers.

TABLE 8
HALF-LIFE (T_h) AND MONOMER YIELD IN THE
PYROLYSIS OF SOME POLYMERS

Polymer	T_h	Monomer *
	$^{\circ}\text{C}$	%
Polytetrafluoroethylene (teflon)	509	> 95
Polymethylene	414	Trace
Polytrifluoroethylene	412	0
Polybutadiene	407	2
Branched Polyethylene	404	Trace
Polypropylene	387	0.2
Polychlorotrifluoroethylene (Kel-F)	380	27
Poly- β -deuterostyrene	372	39
Polystyrene	364	40
Poly- α -deuterostyrene	362	68
Poly- m -methylstyrene	358	45
Polyisobutylene	348	20
Poly(methyl acrylate)	328	Trace
Poly(methyl methacrylate)	327	91
Poly- α -methylstyrene	286	> 95

* In weight percent of total volatilized part.

- d. Breakdown into large chain fragments and small molecules, not particularly related to the structural unit of the polymer. A typical example is methyl methacrylate, which when pyrolyzed at temperatures below 500°C yields mainly carbon dioxide and methyl alcohol. Other examples are vinyl chloride, vinyl fluoride, vinylidene fluoride, and acrylo-nitrile polymers. The chloride, the fluoride, and the nitrile polymers decompose to yield, in addition to large polymer fragments, HCl, HF, and HCN, respectively.

Only a very crude estimation of off-gassing from inspection of chemical composition is possible in terms of the kinds of molecules that could possibly be generated during the breakdown of polymers. Thus polymers containing chlorine may evolve hydrogen chloride and possibly, phosgene. Polymers containing nitrogen may evolve ammonia and various oxides of nitrogen. In general, hydrocarbon type polymers will give off various hydrocarbon products of degradation such as methane, ethylene, and longer chain hydrocarbons. For ready reference, Appendix E lists the chemical composition of the more important polymers likely to be used in manned spacecraft.

Test Method

Studies of the thermal degradation of polymers are performed by pyrolyzing representative samples. Reliable and reproducible measurements are obtained only through careful control in sampling and pyrolysis, and high precision in detection of the weight loss and in the separation and identification of the volatile constituents. The slow process of diffusion of degradation products through the viscous mass of the decomposing polymer must be considered in the sampling step and in the choice of pyrolysis technique. As the pyrolysis temperature is increased, viscosity is lowered but reaction between the pyrolysis products may be accelerated. Under most conditions, thin films give best results. The type of information desired, whether it is identification of a polymer or the analysis of the gaseous products, determines whether pyrolysis should be performed on a hot filament or in a tube furnace. Extensive use has been made of trapping the volatile decomposition products. However, for determination of the composition of the volatiles, gas chromatography, mass spectrometry, or their combination have proven to be the most powerful methods.

For screening purposes the thermogravimetric analysis (TGA) has found almost universal acceptance. In this method weight loss, continuously measured versus time or temperature, provides a rapid method for following the degradation of polymers over a wide temperature range. Detailed degradation kinetics and mechanism investigations can be made conveniently by thermogravimetry, since conditions for vigorous isothermal degradation studies can be quickly selected. Hot-filament pyrolysis is very useful in identification of pyrolysis products. This method can be applied in conjunction with mass or infrared spectroscopy or gas chromatography.

Relative Stability of Polymers

For polymers that vaporize almost completely on pyrolysis at temperatures below 600°C, the relative stability may be established by heating them under exactly the same conditions for a specified period of time and comparing the amount of sample volatilized. Figures 3 and 4 (Ref. 11) show experimental data obtained during vacuum pyrolysis.

Each circle represents a separate experiment of 30 minutes duration at the indicated temperature. The curves, with the exception of vinyl chloride, vinylidene fluoride, and acrylo-nitrile polymers, have generally the same shape, and the relative thermal stability of the represented polymers is quite obvious. However, another convenient method of representing relative thermal stability is to compare characteristic temperatures (T_h) which is the temperature in degrees C at which 50% of the original polymer weight is lost. A series of polymers arranged in the order of their decreasing thermal stability, based on T_h values, is shown in Table 8.

Polymers such as polyvinyl chloride, polyacrylonitrile, and polyvinylidene fluoride, which develop crosslinking during pyrolysis, or polytrivinylbenzene, which is highly crosslinked initially, do not vaporize completely. In such cases a more appropriate scale of comparison would be the amount of residue remaining after pyrolysis and the extent of carbonization of the residue.

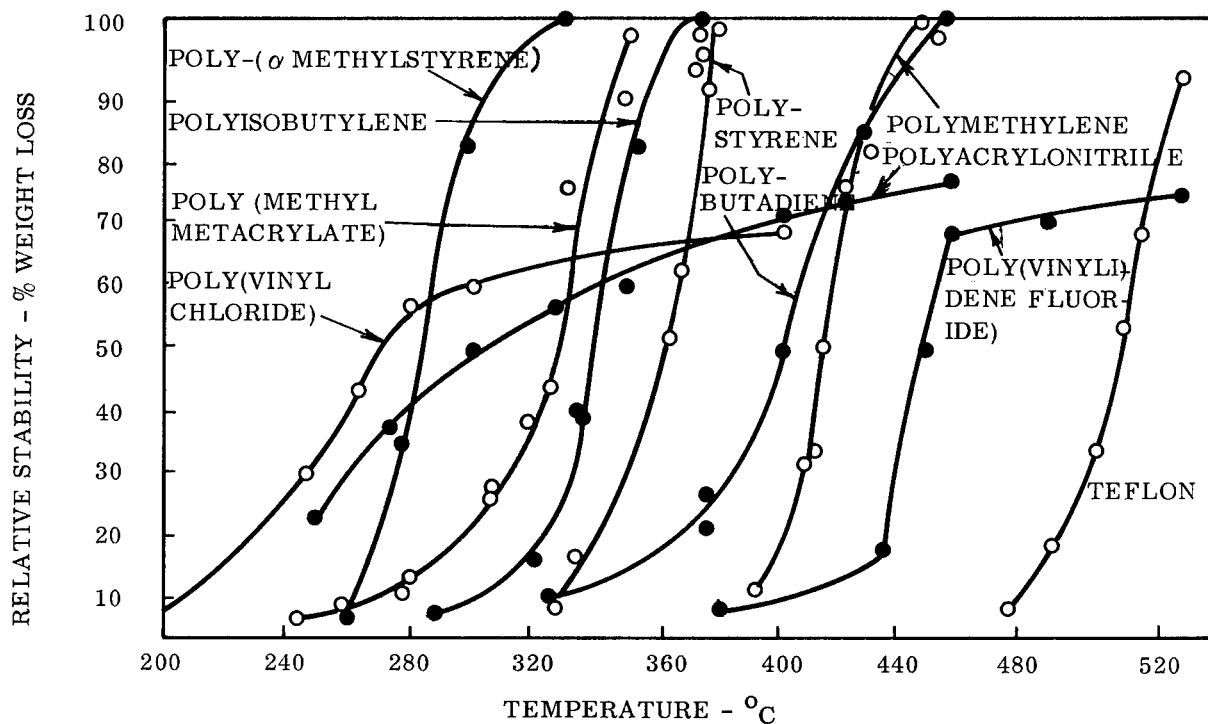


Figure 3. Relative Thermal Stability of Polymers at Lower Temperatures

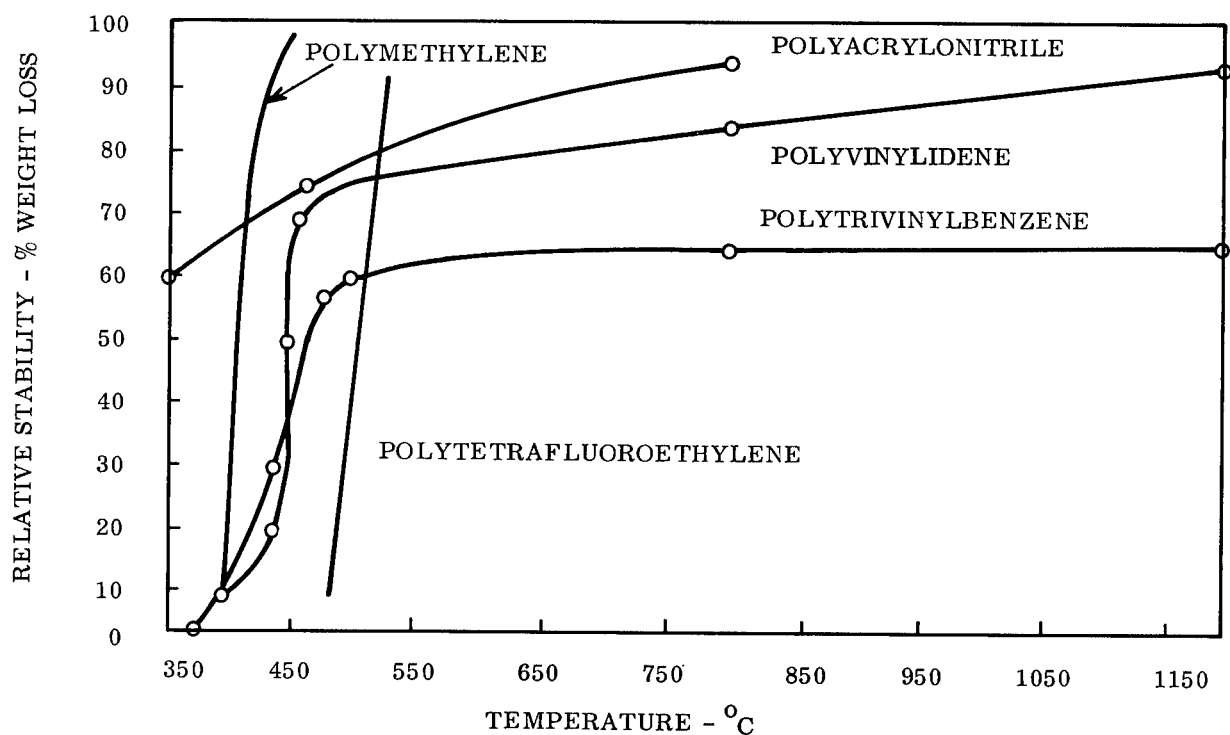


Figure 4. Relative Thermal Stability of High-Temperature Polymers

Breakdown Products

Madorsky and Straus (Ref. 12) performed an extensive study of polymer degradation at temperatures up to 1200°C. The study included identification of the constituents of degradation products, determinations of fraction of the samples volatilized at various temperatures, and obtaining the rates of degradation of the polymers under investigation. The representative polymers studied were:

- a. Polyester (Vibrin 136A), consisting of equal parts by weight of maleic anhydride and triallyl cyanurate, with tertiary butyl perbenzoate as the curing agent.
- b. Epoxy (Epon 1310) which is a condensation product of epichlorohydrin with a polyphenol containing 3 to 4 phenolic groups per molecule and having a molecular weight of 200 per epoxide group. Boron trifluoride was used as the curing agent.
- c. Phenolic (phenol-formaldehyde resin).
- d. Silicone with methyl and phenyl groups attached to silicon atoms in a silicon-oxygen chain.
- e. Polyvinylidene fluoride polymerized by γ -radiation.
- f. Polytrivinylbenzene.
- g. Polyacrylonitrile.
- h. Polymethylene.
- i. Copolymers of styrene with divinylbenzene and trivinylbenzene.

Tables 9 through 14 illustrate typical results. Note that the component quantities vary as a function of pyrolysis temperature.

In still another comprehensive study of thermal degradation of polymers, Grundfest (6) (Ref. 13) reported results shown in Tables 16 and 17. Table 15 identifies the polymers investigated.

In June 1958, the Pyrolysis Task Group of the ASTM E-14 Committee on Mass Spectrometry prepared an annotated bibliography on the subjects of pyrolysis and depolymerization. This bibliography is reproduced herein for reference purposes in Appendix F. A more recent and more inclusive bibliography on the subject of degradation of materials was also prepared and is included as Appendix G.

One factor common to past studies of the thermal degradation of polymers is the relatively high temperatures involved as compared to those existing within a manned spacecraft. No data at ambient temperatures and in the presence of high oxygen concentration atmospheres was discovered. The high temperature data is significant,

however, in revealing the probable toxic contaminants which may be generated at lower temperatures even though the rate of generation may be such that no problem is anticipated.

PROPOSED SPACECRAFT MATERIALS

Current Programs

Listed in the Appendix are specific materials which have been indicated for potential use in the following spacecraft:

- Apollo - Appendix A
- Mercury - Appendix B
- Dynasoar (X-20) - Appendix C

The information obtained was qualitative in nature rather than quantitative. With quantitative information, it would have been possible to assess the probable rate of accumulation of the toxic products of these materials. Unfortunately, quantitative materials data have not been compiled by any of the sources contacted. Moreover, the data as available were incomplete and no assurances could be given that all of the materials listed would be finally approved for use.

TABLE 9
THERMAL DEGRADATION OF POLYMERS
IN A VACUUM AT VARIOUS TEMPERATURES (REF. 12)

Polymer	Temperature of Pyrolysis, °C					
	500°	800°			1200°	
	Vol *	M**	Vol	M	Vol	M
	%		%		%	
Vibrin	83	73	89	49	93	39
Epoxy	75	146	86	71	87	36
Phenolic	28	76	47	24	48	41
Poly(vinylidene fluoride)	76	29	85	29	90	29
Polytrivinylbenzene	55	162	68	57	63	40
Polymethylene	100	583	98	230	98	30
Polystyrene***	---	---	100	141***	--	--

*Vol - stands for volatilization in percent of sample.

**M - stands for average molecular weight of all volatiles.

***Figures for polystyrene are based on results of pyrolysis at 850°C.

TABLE 10

ANALYSIS OF VOLATILE PRODUCTS FROM PYROLYSIS
OF THERMOSET PLASTICS IN A VACUUM AT 1200° (Ref. 12)

Component *	Vibrin	Epoxy	Phenolic
	%	%	%
H ₂	1.3	2.1	2.8
CO	7.2	25.9	2.2
CO ₂	29.4	1.8	1.2
CH ₄	3.4	4.3	4.9
C ₂ H ₂	0.1	2.5	1.9
C ₂ H ₄	14.8	3.0	1.6
C ₃ H ₄	0.1	0.4	0.3
C ₃ H ₆	1.6	0.1	0.8
C ₄ H ₆	1.4	0.2	0.1
C ₅ H ₆	1.3	0.6	0.9
C ₆ H ₆	4.7	8.1	9.0
C ₇ H ₈	0.1	0.1	1.5
V _{pyr}	38.2	50.9	72.8
Total	100.0	100.0	100.0
Volatilization, % of Sample	93	87	48

* Amounts of components are given in weight percent of total volatilized part.

TABLE 11

ANALYSIS OF VOLATILE PRODUCTS FROM PYROLYSIS
OF POLYTRIVINYLBENZENE IN A VACUUM (Ref. 12)

Component*	Temperature of Pyrolysis		
	500° C	800° C	1200° C
	%	%	%
H ₂	0.1	2.1	3.3
CH ₄	1.7	5.0	4.8
C ₂ H ₂	---	---	3.3
C ₂ H ₄	1.8	0.7	3.3
C ₂ H ₆	1.5	0.9	0.1
C ₃ H ₄	0.1	0.1	---
C ₃ H ₆	1.0	1.4	0.1
C ₃ H ₈	0.8	0.3	0.1
C ₄ H ₈	0.8	0.2	0.1
C ₅ H ₁₀	0.1	0.1	---
C ₆ H ₆	0.1	0.2	4.0
C ₇ H ₈	0.2	0.4	0.3
C ₈ H ₈	0.1	0.1	---
C ₈ H ₁₀	1.2	0.8	---
C ₉ H ₁₀	0.8	0.2	---
C ₉ H ₁₂	2.4	1.0	---
C ₁₀ H ₁₄	1.9	0.4	---
C ₁₁ H ₁₆	0.6	0.1	---
V _{pyr} **	84.8	86.0	80.6
Total	100.0	100.0	100.0
Volatilization, % of Sample	55	68	63

* Amounts of components are given in weight percent of total volatilized part.

**Pyrolysis products not volatile at room temperature.

TABLE 12

ANALYSIS OF VOLATILE PRODUCTS FROM PYROLYSIS
OF POLYMETHYLENE IN A VACUUM (Ref. 12)

Component*	Temperature of Pyrolysis		
	500° C	800° C	1200° C
	%	%	%
H ₂	---	0.1	1.5
CH ₄	---	0.4	5.8
C ₂ H ₂	---	0.1	4.9
C ₂ H ₄	0.1	2.7	40.1
C ₂ H ₆	---	0.1	0.7
C ₃ H ₄	---	0.1	5.6
C ₃ H ₆	0.1	1.9	11.4
C ₃ H ₈	0.1	0.2	0.5
C ₄ H ₄	---	---	2.9
C ₄ H ₆	0.1	0.5	7.7
C ₄ H ₈	0.1	1.7	2.7
C ₄ H ₁₀	0.1	0.1	---
C ₅ H ₆	---	---	1.1
C ₅ H ₈	---	0.5	2.0
C ₆ H ₆	---	0.1	1.6
C ₆ H ₁₀	0.2	0.4	---
C ₆ H ₁₂	0.4	1.2	---
C ₆ H ₁₄	0.2	0.3	---
C ₇ H ₁₂	0.2	0.3	0.5
C ₇ H ₁₄	0.7	1.2	---
C ₇ H ₁₆	0.4	0.2	---

*Amounts of components are given in weight percent of total volatilized part.

TABLE 12 (Continued)

ANALYSIS OF VOLATILE PRODUCTS FROM PYROLYSIS
OF POLYMETHYLENE IN A VACUUM (Ref. 12)

Component*	Temperature of Pyrolysis		
	500° C	800° C	1200° C
	%	%	%
C ₈ H ₁₆	---	0.4	---
C ₈ H ₁₈	---	0.1	---
C ₉ H ₁₈	---	0.1	---
V _{pyr} **	97.3	87.3	11.0
Total	100.0	100.0	100.0
Volatilization, % of Sample	99.2	99.8	98.3

* Amounts of components are given in weight percent
of total volatilized part.

**Pyrolysis products not volatile at room temperature.

TABLE 13

RATES OF THERMAL DEGRADATION OF THERMOSET PLASTICS (Ref. 12)

Polymer	Pyrolysis Temp. °C	Heating Duration min	Loss of Weight	
			Amount %	Rate %/min
Epoxy	340	250	39	0.311 at 0% loss*
	350	260	47	0.575 "
	360	220	51	1.160 "
Vibrin	350	150	28.4	0.210 at 18% loss
	360	340	41.7	0.310 "
	370	350	50.7	0.520 "
	350	150	28.4	0.167 at 20% loss
	360	340	41.7	0.249 "
	370	350	50.7	0.455 "
	380	230	51.0	0.650 "
	350	150	28.4	0.125 at 22% loss
	360	340	41.7	0.204 "
	370	350	50.7	0.385 "
Phenolic	350	150	28.4	0.085 at 24% loss
	360	340	41.7	0.167 at "
	370	350	50.7	0.318 "
	350	150	28.4	0.057 at 26% loss
	360	340	41.7	0.102 "
	370	350	50.7	0.244 "
	355	110	9.6	0.092 at 7% loss
	380	100	10.1	0.154 "
	331.5	1200	10.4	0.033 -----

*Values at 0% loss were obtained by extrapolation of curve.

TABLE 14

RATES OF THERMAL DEGRADATION OF POLY(VINYLDENE FLUORIDE),
POLYACRYLONITRILE, AND POLYTRIVINYLBENZENE IN A VACUUM (Ref. 12)

Polymer	Temp. °C	Heating Duration		Loss of Weight	
				Amount	Rate*
Poly(vinylidene fluoride)	371.3 390 400 410 420	hr	min	%	%/min
				47.6	0.14
				49.9	0.36
				55.5	0.66
				58.0	1.15
Polyacrylonitrile	218 228 240 250 260	hr	min	62.5	2.15
				6.0	0.01
				9.7	0.05
				11.8	0.36
				14.0	0.63
Polytrivinylbenzene	394 420 430 440	hr	min	16.5	1.14
				38.2	0.03
				45.2	0.28
				46.0	0.59
				47.8	1.22

* Rates for poly(vinylidene fluoride) and polyacrylonitrile were obtained from maxima of the rate curves; rates for trivinylbenzene are based on initial rates obtained by extrapolating the rate curves to zero loss.

TABLE 15
MATERIALS STUDIED (Ref. 13)

	<u>% of Resin by wt.</u>	<u>Symbol</u>
CTL-91LD on glass (Commercial high temperature phenolic resin)	(22)	(CTL)
Taylor Phenolic (Electrical grade on glass)	(44)	(Taylor)
Melamine on glass (Textolite 11508)	(46)	(Melamine)
Epoxy on glass (Shell 828)	(45)	(Epoxy)
Novolac epoxy on Refrasil (Dew 2638.1)	(46.6)	Novolac R
Novolac epoxy on Asbestos (Dew 2638.1)	(42)	Novolac A
Polyester (Vibrin 1068)	100	Polyester
Nylon	100	Nylon
Treated nylon (impregnated with phosphotungstic acid)	100	Nylon T
Cotton	100	Cotton
Treated cotton (impregnated with phosphotungstic acid)	82	Cotton T

TABLE 16

CHAR AND GAS PRODUCED IN TUBE FURNACE EXPERIMENTS (Ref. 13)

<u>Resin</u>	<u>Temp (°C)</u>	<u>Char (%)</u>	<u>Relative Vol Gas cc/gm</u>	<u>Average N. W.</u>	<u>% Tar</u>
CTL	460	84.37	15.63	22.3	----
	500	73.32	13.40	18.2	11.27
	560	68.19	31.81	16.1	----
	610	65.27	34.73	10.5	----
	650	61.46	38.54	11.3	----
	700	60.19	39.81	10.3	----
	720	61.88	38.12	11.4	----
	800	60.51	27.9	7.8	11.59
	900	55.78	28.16	19.2	16.06
	1000	55.41	31.69	15.6	12.9
	1000	54.90	37.58	10.8	7.52
Taylor	500	58.53	22.73	20.8	18.74
	720	46.03	37.07	20.2	16.90
	1000	42.90	37.24	10.4	19.86
Melamine	500	41.68	6.61	20.88	51.71
Epoxy	600	13.86	15.10	27.4	71.04
	800	9.35	21.12	41.0	69.53
	1000	6.62	31.91	32.2	61.47
Novolac R	600	16.98	33.85	35.98	49.17
	800	10.88	8.71	24.1	80.41
Novolac A	600	16.97	23.37	32.2	59.66
	800	11.38	43.15	22.7	45.47
Polyester	600	5.48	17.87	40.2	76.65
Nylon	600	10.22	-----	28.4	91.76
	800	33.76	-----	22.5	X
Nylon T	600	32.87	1.3	16.4	65.82
	800	33.16	39.37	18.5	27.47
Cotton	600	4.75	29.62	19.2	65.63
	800	49.07	42.57	31.9	8.36
Cotton T	800	43.18	43.19	26.9	13.63

TABLE 17

MAJOR GASEOUS PYROLYSIS PRODUCTS (Ref. 13)

Resin	Temp.	% H ₂	% CO	% CO ₂	% CH
CTL	460	23.15	63.94	4.41	6.61
	500	25.22	20.17	6.73	17.64
	560	37.43	25.15	5.93	21.06
	610	56.38	13.09	6.26	21.6
	650	59.39	15.76	6.66	17.58
	700	57.69	20.39	X	16.43
	720	46.53	18.83	2.77	16.62
	800	72.99	11.26	2.18	11.43
	900	33.16	55.28	4.15	5.40
	1000	40.74	40.74	2.22	7.41
	1000	54.80	17.	1.47	12.64
Taylor	500	21.76	10.12	15.38	25.02
	720	49.54	17.54	2.99	21.67
	1000	65.84	23.23	3.09	----
Melamine	500	(22% ethane, 70.48% NH ₃ , 6.5% CH ₃ CH, CH ₃ OH)			
Epoxy	600	13.33	22.93	28.67	14.33
	800	27.14	15.08	21.72	15.08
	1000	28.27	18.49	23.92	8.92
Novolac R	600	7.68	24.49	31.06	(1.7% acrolein)
	800	35.41	11.36	19.26	(6.6% acrolein, 4% acetone)
Novolac A	600	24.24	----		
	600	11.06	36.09	32.40	(5% acrolein, 1.44% acetone)
	800	34.88	----		(8.0% acrolein, 9.8% acetone)
Polyester	600	3.29	9.10	58.42	
Nylon	600	18.18	(analyses poor)		
	800	14.16	25.66	10.62	14.16 (12.39% Ethylene)
Nylon T	600	9.52	(analyses poor)		
	800	37.71	22.38	6.86	8.66
Cotton	600	9.5	35.63	26.13	9.26
Cotton T	600	2.39	58.80	33.43	
	800	14.86	60.45	22.16	

The Life Sciences Group of the North American Aviation Corp. has compiled a list of materials, Appendix A, which are being considered for the command module of the Apollo spacecraft. This list is approximately 50 percent complete. Outgassing studies have been initiated by North American which are limited to a literature search effort. Beginning in January or February 1963 actual testing of the materials will be undertaken, utilizing gas chromatographic techniques.

The Boeing Company has compiled a list of materials, Appendix C, which had been arbitrarily selected and were not specifically identified for use in the X-20 program. This list is estimated to be approximately 30% complete. In the development state of the X-20 program, toxicity investigation is being limited primarily to an analysis and literature search. During preliminary flight rating tests of flight prototype hardware, subsystems and components will be checked for evolution of noxious or toxic products. The Boeing Company has, however, done some laboratory investigations of the thermal decomposition products of selected materials by means of the thermogravimetric analysis (TGA) method. The data from these studies are presented in Appendix D.

The Materials and Processes Group of the McDonnell Aircraft Corp. has been engaged in materials toxicity investigations since 1959. Their technique has been to determine the temperature limits of selected materials in a 100% oxygen and 5 psia environment for 24 hours continuous usage without producing any of the following:

- Irritating or obnoxious odors - "sniff" tests were conducted on the effluent of the materials.
- Toxic gases - no animal tests were conducted. In general, the gases were classified as toxic if the odor was irritating. (Note: This is not considered an acceptable test for toxicity.)
- Chemical deterioration (oxidation).
- Spontaneous flash fire or explosion due to gaseous products or the solid materials as such.

Additional tests were conducted by McDonnell to determine the physico-chemical effects of H_2O_2 spillage on selected non-metallic materials. This test reflects the concern about the reactions of H_2O_2 , used in the Mercury attitude control system, with other spacecraft materials. The data obtained as a result of these evaluations are included together with the lists of materials in Appendix B. This list is estimated to be 65% complete.

As previously noted, the quantities of the various materials noted in Appendices A through C for each corresponding spacecraft are not currently available. Without reference to specific hardware, it is impossible to determine a precise and completely meaningful weight breakdown analysis by material type. As an approximation, qualitative data for types of equipment can be generated for estimating purposes. For example, electronic type instruments may be considered to be composed of materials as shown in Table 18. Thus, for a four man orbiting space station containing about

TABLE 18
COMPOSITION OF ELECTRONIC EQUIPMENT⁽¹⁾

Materials	Weight in Grams per Kilogram
<u>Metals</u>	
Alloy resistance wire (Evenohm)	1
Aluminum (unfinished)	25
Aluminum (anodized)	210
Brass	133
Chromium	Trace
Cobalt	Trace
Copper	50
Copper (tinned)	35
Ferrous metal	10
Ferrous metal (hi mu)	5
Germanium ⁽²⁾	16
Gold	Trace
Lead	5
Manganese	Trace
Molybdenum	Trace
Nickel	13
Selenium	Trace
Silicon ⁽²⁾	12
Tantalum ⁽²⁾	18
Tin	4
	<hr/> 537
<u>Non-Metals</u>	
Carbon ⁽²⁾	3.8
Ceramic	20
Epoxy (Hysol) ⁽³⁾	110
Epoxy (MPC 52 w/ceramic speres)	200
Formex (insulating enamel)	0.2
Glass	11
Glass (fiber)	7
Kel-F (plastic)	4
Mylar (metallized) ⁽²⁾	36
Plastic (misc.)	38
Teflon	23
Miscellaneous	10
	<hr/> 463
	Total 1,000

(1) Materials breakdown averaged across three typical electronic chassis designed for flight in Project "Advent".

(2) Encapsulated, as in transistors, capacitors, etc.

(3) Large surface area.

TABLE 19

SUBMARINE ATMOSPHERE CONTAMINANTS

Compounds Identified or Suspected in Submarine Atmospheres

Compound	Chemical Formula	Suspected Source	Remarks
Acetylene	C_2H_2		
Acrolein	$CH_2CH\ CHO$	Cooking	
Arsine	AsH_3	Battery Gassing	
Ammonia	NH_3	Scrubbers	
Carbon Dioxide	CO_2	Breathing	
Carbon Monoxide	CO	Smoking	
Chlorine	Cl_2	Chlorate Candles	
Ethylene	C_2H_4	Polyethylene Decomposition	
Formaldehyde	CH_2O	Cooking, Combustion	
Freon-12	CCl_2F_2	Air Conditioning	See also HCl , HF , and $COCl_2$
Hydrocarbons (other than CH_4)	--	Paints	
Hydrogen	H_2	Battery Gassing	
Hydrogen Chloride	HCl	Freon Decomposition	
Hydrogen Fluoride	HF	Freon Decomposition	
Methane	CH_4	Sanitary Tanks	
Methyl Alcohol	CH_3OH		
Monoethanolamine	$HOCH_2CH_2NH_2CO_2$	Scrubbers	
Nitrogen	N_2		
Nitrogen Dioxide	NO_2	Burners, smoking	
Nitric Oxide	NO	Burners, smoking	
Oxygen	O_2		
Ozone	O_3	Precipitators	
Phosgene	$COCl_2$	Freon Decomposition	

TABLE 19

SUBMARINE ATMOSPHERE CONTAMINANTS (Cont'd.)

Compounds Identified or Suspected in Submarine Atmospheres (Cont'd.)

Compound	Chemical Formula	Suspected Source	Remarks
Stibine	SbH_3	Battery Gassing	Highly unstable
Sulfur Dioxide	SO_2	Oxidation Sanitary Tank Gases	
Triaryl Phosphate (NOTE 4)	--	Compressors	

Compounds Qualitatively Identified in Trace Amounts

Material	Chemical Formula	Material	Chemical Formula
Arsine	AsH_3	Propane	C_3H_8
Benzene	C_6H_6	Pseudocumene	$1,2,4-(\text{CH}_3)\text{C}_6\text{H}_3$
1-3-Dimethyl-5-ethyl-benzene	$1,3-(\text{CH}_3)_2-5-\text{C}_2\text{H}_5\text{C}_6\text{H}_3$	Sulfur Dioxide	SO_2
Ethylene	C_2H_4	Toluene	$\text{C}_6\text{H}_5\text{CH}_3$
p-Ethyl Toluene	$1,4-\text{CH}_3\text{C}_2\text{H}_5\text{C}_6\text{H}_4$	O-xylene	$1,2-(\text{CH}_3)_2\text{C}_6\text{H}_4$
Freon-114	$\text{CF}_2\text{ClCF}_2\text{Cl}$	m-xylene	$1,3-(\text{CH}_3)_2\text{C}_6\text{H}_4$
"Gasoline Vapors"	-	p-xylene	$1,4-(\text{CH}_3)_2\text{C}_6\text{H}_4$
Hydrogen Chloride	HCl		
Mesitylene	$1,3,5-(\text{CH}_3)_3\text{C}_6\text{H}_3$		

Compounds Suspected as Present But Not Identified

Material	Chemical Formula	Suspected Source
Formaldehyde	HCHO	Oxidation of Methyl Alcohol
Mercury	Hg	Meters and gauges
Ozone	O_3	Electronic/electrical Equipment
Acrolein	CH_2CHCHO	Cooking fats and greases
Phosgene	COCl_2	Degradation of Freon
Hydrogen Sulfide	H_2S	Waste tanks
Radon, etc.	Rn	Luminous dials
Cellulube 550	(triaryl Phosphate)	Hydraulic fluids
Sodium Bisulfate	NaHSO_4	CO_2 scrubber

300 lbs. of internally located electronic equipment, some 127 lbs. of material (from which toxic contaminants may be generated) may be included. Note that the majority of these objectionable materials are plastics and mainly epoxy base resins. Actually the quantity required to contaminate the spacecraft atmosphere may be small (assuming no atmosphere leakage). Thus, assuming a 1000 ft³ free volume enclosure and using the data of Table 10, the degradation of greater than 0.06 lbs. of epoxy would result in a carbon monoxide concentration exceeding ACGIH limits. The above table illustrates the degree to which equipment materials must be considered if toxic hazards are to be eliminated.

Submarine Atmosphere Contaminants

Naval submarine activities have long been confronted with problems of contamination of submarine atmospheres. The more recent development of the nuclear submarine has, because of its long range capability, introduced habitability problems that had not been encountered previously. An intensive atmosphere test program was therefore set up in 1956. References 14 through 16 indicate the results of this program.

Table 19 (Ref. 14) gives evidence of the broad spectrum of contaminants that have been found or suspected to occur in nuclear and fleet submarines. Although problems of the submarine and manned spacecraft are divergent in many respects, they parallel each other in a number of ways. It is therefore expected that many of the contaminants contained in submarine atmospheres, particularly nuclear powered, will also be present in manned spacecraft.

An interesting point noted in Reference 16 emphasizes the need for toxic contaminant monitoring in spacecraft. This is in reference to the fact that the toxic contaminant control equipment on-board the spacecraft may, in its operation, cause the generation of toxic contaminants. Catalytic burners using Hopcalite are commonly used in submarines (and spacecraft) for control of CO and H₂ and for removal of many organic contaminants. However, if freons are present, hydrogen fluoride is formed as a product of the catalytic combustion to the detriment of crew and equipment.

DETECTION AND IDENTIFICATION METHODS

In the selection and design of equipment to detect and identify potentially hazardous materials which may be present in spacecraft atmospheres, several concepts must be examined. The final selection will depend upon such factors as the extent of equipment required for removal of the contaminants, the type and extent of identification required, the power, weight, and volume which can be allocated for such instruments, the degree of reliability required, and the extent of participation of the occupant in preparation of such equipment and evaluation of results. As described in Section 2.0, the hazardous materials will be present in two general forms, gases and vapors, or particulate matter.

GAS AND VAPOR CONTAMINANTS

The toxic vapor detection and identification methods employed for a specific space mission will depend to a great extent on the duration of the mission and secondarily on whether the mission is earth orbital or interplanetary. Toxic gas monitoring instrumentation could vary from no instrumentation or at most one or two specific gas sensors during a short mission such as a ballistic shot or earth orbital flight, to highly sophisticated laboratory-type analytical equipment carried in massive manned space stations over mission periods of many months. The decision to carry certain sophisticated multiple-gas type instrumentation might depend on the particular stress the spacecraft is expected to encounter; for example, high intensity ionizing radiation. In this connection the height of the orbital path above the earth during a sustained earth orbital mission could in a large measure determine the extent of the instrumentation.

For these reasons, in the discussion to follow covering multiple-gas detectors and specific gas detectors and even more extensively in the section covering instrumentation specifications as the basis for a compact toxic gas monitoring kit, mission type and duration will be a strong factor. Note also that vapor is synonymous with gas insofar as detection and identification are concerned.

Multiple Gas Instruments

The term multiple gas detector is here used to define a single instrument whose theory of operation makes it capable of detecting, identifying and making quantitative determinations of two or more gases. Generally, a multiple gas detector can make determinations of more than two gases, usually upwards of five gases. Several of the multiple gas sensors, among them the mass spectrometer and infrared spectrophotometer, can make determinations of literally hundreds of all gases (not in a single mixture) depending upon the particular gas mixtures analyzed.

Many instrumentation techniques for multiple-gas or material analysis were subjected to a preliminary literature investigation and, as a result of the investigation, ruled out for application to space flight. Among these were: Cryoscopy, Emission Spectrometry, X-ray Fluorescence, X-ray diffraction, Nuclear Magnetic Resonance, Activation Analysis, and Microwave Spectroscopy. Most were discarded because their operation could not be reasonably compatible with the spacecraft environment due to sample preparation and analysis-energy-source requirements. Others were

not included due to predicted high weight and volume requirements for a space flight package, or highly complex analysis procedures. An amperometric method for the determination of concentrations of several gases in the parts per million range, has been developed (Ref. 17). In this method advantage is taken of the fact that the diffusion current between two electrodes to which an EMF is applied is a function of the concentration of the given trace gas in a mixture with other inert gases. The method, while very sensitive and reproducible, is not as yet specific enough to distinguish a particular gas in the presence of other reactive gases.

Mass Spectrometer. The mass spectrometer is an analytical instrument which identifies gases by determining their mass-to-charge ratio (essentially their molecular weight). Its output is a voltage peak, the amplitude of which is a function of the concentration of the gas, and whose position in time varies directly with the mass-to-charge ratio. Mass spectrometers utilize several techniques for separating these gases in time in accordance with their mass-to-charge ratios. Most widely used are the magnetic deflection types, time-of-flight types, and high frequency types. While the high frequency type instrument is not in wide use in the laboratory, it could well be the mass spectrometer of choice in a gas analytical system for space flight, since it appears that it can be packaged most efficiently from a volume and weight standpoint, and even more important it does not require a magnetic field (discussed later) of any type for its operation.

Any mass spectrometer, when used alone as an instrument for analyzing gaseous mixtures at near normal room temperatures and pressures, does not possess a sensitivity higher than about one part per million under ideal laboratory conditions. Rapid scan mass spectrometers, such as the time of flight type, cannot be depended upon consistently to deliver better than about 10 parts per million. When packaged for space flight this sensitivity figure will probably be even further degraded. Also these sensitivity figures are only valid when the adjacent mass peak is either several mass units removed from the peak of interest, or of equal or less concentration so peak "overlap" interference is minimized.

Physiologically, allowable concentrations of toxic contaminants are generally much less than 10 parts per million and many are less than one part per million; some even fall below 100 parts per billion (Ref. 18). Thus, the unaided mass spectrometer will fail to "see" a great many of the peaks of interest due to low sensitivity and interference from the high concentration fixed gases such as oxygen and nitrogen.

The electromagnetic deflection, and time of flight instruments are not ideally suited for long range space missions since they require electromagnets or permanent magnets of high gauss for proper operation of the instruments. An actual magnetic field measurement using a magnetometer was made at a distance of 12 inches from a time of flight mass spectrometer (Bendix Model 12). A magnetic field strength of 10 gauss maximum was recorded. Depending on the spacecraft mission, the electromagnetic fields generated by on-board equipment range from insignificant to intolerable. Even shielding does not sufficiently attenuate such hi-gauss fields. There are several effects:

- a. Vehicle Torque - Interaction of a strong magnet with Earth's field produces torques on the vehicle, which, depending on the distance from earth, may

be the largest disturbance to vehicle attitude. For altitudes up to 20,000 nautical miles or more small size magnets produce greater torques than solar pressure or other pressures and are sufficient to be used in control systems to remove accumulated momentum from central flywheels.

- b. Distortion of Field - Many vehicles carry magnetometers to read inter-planetary magnetic fields, either to obtain data or to resolve currents among torquing coils. These will be nullified by the presence of a large artificial field in the vehicle.
- c. Instrumentation - In some cases operation of guidance or control instrumentation may be susceptible to magnetic fields that can exist near devices with large magnets.

These and other factors are sufficiently important that component specifications for some vehicles have quoted stringent requirements with respect to inherent magnetic fields.

Two important advantages of the mass spectrometer are: the extremely small sample size required (Approx. 0.2 cc/min at 0.2 mm of pressure) and the inherent ability to "see" an unknown gas by its molecular weight. Thus, an unpredicted gas, provided its concentration was above the instrument threshold and provided high concentration masking gases were absent, could not go unnoticed.

Gas Chromatograph. A gas chromatograph consists basically of 3 parts: the sampling system, a column and a detector. Helium is generally used as a carrier gas; however, argon, nitrogen and hydrogen have also been used and, no doubt, several other gases have been used experimentally. Commonly, the detector is a device which generates either a zero electrical signal, or a DC electrical signal when only the carrier gas is passing through it, but delivers a varying signal, or AC signal when any other gas appears mixed with the carrier gas. The AC signal is also normally proportional in amplitude to the concentration of the contaminating gas in the carrier.

In operation, carrier gas is allowed to flow through the entire system at a rate between 10 and 400 cc per minute, the exact rate of flow depending upon the particular equipment at hand and the type of analysis being performed. The carrier gas allows the various gases in the sample mixture to lag the carrier due to the selective retardation exerted by the stationary phase. The carrier gas sweeps the sample gas mixture through the column containing the solid adsorbing or liquid partitioning agents. Thus the components of the mixture move through the column, effectively at different flow rates.

It should be noted that the partitioning columns are designed for specific mixtures of gases. An unknown (and thus unexpected) trace gas could therefore not be detected. This is an important and often unrealized disadvantage of the gas chromatograph for toxic contaminant detection and identification. The detector in a gas chromatograph is probably the most critical component of the entire instrument. It is the detector which determines the ultimate sensitivity of the instrument and determines also to a large extent the types of gases which can be detected. Several of the most widely used detectors, as well as a new detector which shows great promise, are briefly described.

a. Thermal Conductivity Detector. This detector depends for its operation upon the differential thermal conductivity of different gases. Hot wire elements or thermistors are generally used. This type of detector has two outstanding advantages. It requires very simple output circuitry, and it will detect any gas of sufficient concentration whose thermal conductivity is different from that of the carrier gas. On the deficit side of the ledger, however, is its poor sensitivity; it cannot be depended upon to deliver a sensitivity of better than 100 parts per million and most generally the sensitivity is on the order of 500 parts per million to many of the gases of interest. In the realm of toxic gas detection this detector is useless, since most MAC's require much higher sensitivity levels for measurement (Ref. 18).

b. Hydrogen-Flame Ionization Detector. The hydrogen-flame ionization detector, as in the case with most ionization detectors, is between 10^3 and 10^4 times more sensitive than the thermal conductivity detector. The one advantage of this detector is its high sensitivity to certain gases. The detector is insensitive to inorganic compounds, except for some containing elements in groups I and II of the periodic table. It will respond to all organic substances except formic acid, CO_2 and CO . Its sensitivity to organic compounds is approximately proportional to the carbon number, except for those compounds which are oxygenated or contain nitrogen. Calibration is very critical in this detector for quantitative results, and is much dependent upon detector design and gas flow rate. The sophistication of this detector, its critical nature and the fact that a hydrogen flame is required, would appear to make it unsuitable for spacecraft use.

c. Argon Ionization Detector. Several versions of this detector have been developed, with much of the work being done by J. E. Lovelock (Ref. 19). These versions have varied from models with sensitivities not much better than a thermal conductivity detector, to sensitivities even higher than some hydrogen-flame ionization detectors. Again, the sole advantage of the argon ionization detector lies in its high sensitivity. It has an additional advantage over the hydrogen-flame detector in that a flame is not required. However, the same sophisticated readout circuitry is required.

The argon ionization detector will detect most organics and in addition, some of the simple gases not detectable with the hydrogen flame, such as H_2O , NO , NO_2 , NH_3 , PH_3 , BF_3 , and others. As with the hydrogen-flame ionization detector, the argon detector will not respond to H_2 , N_2 , O_2 , CO_2 , CO , $(\text{CN})_2$, H_2O , and also fluorocarbons. In general, all organics which have ionization potentials of less than 11.7 electron volts can be detected. However, the several critical toxic gases noted above cannot be seen by this detector and therefore, it would appear to be unwise to carry this instrument as the only multiple gas detector on a particular space mission without the inclusion of several backup specific gas detectors.

d. Karmen Glow Discharge Detector. The Karmen Glow Discharge detector is a very recent development in the field of gas chromatography detectors. Dr. Arthur Karmen, et al (Ref. 20 and 21) working in the Technical Development Laboratory of the National Heart Institute with a form of the Lovelock ionization detector, noted that when helium was used as the carrier gas and the intensity of the radioactive source was increased — this normally produces an increase in current in the detector — for a given voltage across the cell, current failed to increase beyond 10^{-7} amps. regardless of the intensity of the radioactive source. When Karmen removed the radioactive

source and operated the detector from a constant current power supply, a stable glow discharge was initiated in the detector. A schematic representation of this detector is shown in Figure 5. The breakdown voltage across the cell was found to be a function of the impurity in the helium. Since the sequential effluent gases, contained in the original sample injected into the column of a gas chromatograph, are essentially contaminants of the carrier gas as they leave the column, Karmen found he had an extremely sensitive detector, which could see the light permanent gases as well as organics.

Sensitivities to several of the light permanent gases measured were as good or better than sensitivities to organics obtained in other ionization detectors. An additional advantage possessed by this detector is that the output signal is biphasic, depending upon the concentration of the particular contaminant. Figure 6 is an approximate plot of this characteristic. As the concentration of the "contaminant" gas in the helium increases from 0 to approximately 100 parts per million, the effective glow discharge resistance reduces and therefore the voltage across the cell goes negative. However, as the concentration continues to increase, a point is reached where the slope abruptly reverses due to partial quenching of the glow discharge due to the high concentration contaminant. The negative going characteristic for the extremely low concentration has the steepest slope, a desirable characteristic for a toxic gas detector.

While this detector has recently been introduced to the art, it is not at present being marketed and perhaps has certain disadvantages which are yet to be discovered. It appears to be a detector which will supply the gas chromatograph with a high sensitivity, as well as an "across the board" detector of essentially all gases that are separated in the column. With the advent of this detector, even with its sophisticated readout circuitry, the use of the gas chromatograph as a multiple toxic gas detector during space missions becomes much brighter.

Spectrophotometers

In the present state of the art of spectrophotometry for gas analysis, two instrument types are much used in the laboratory. One type is the infrared spectrophotometer and the other instrument is the UV and visible spectrophotometer. Between the two instruments including accessories, practically all gases and vapors can be detected provided they are of sufficient concentration. For organic gaseous forms, without resorting to extremely cumbersome methods of handling the sample, only the infrared instrument is of value; sensitivities between 20 and 100 parts per million are feasible.

Spectrophotometric instruments for gas analysis, while valuable as complementary instruments in the laboratory, are considered to pose severe problems where redevelopment and redesign for space vehicle applications are undertaken. In order to achieve even reasonable sensitivity (better than 100 parts per million), complex, long optical path-lengths are required and/or samples at high pressures are necessary. These long path lengths make instrument volume reduction difficult. In addition, the optics required for infrared transmission and refraction are generally adversely affected by high humidity conditions. This could interfere seriously with the reliability of the instrument.

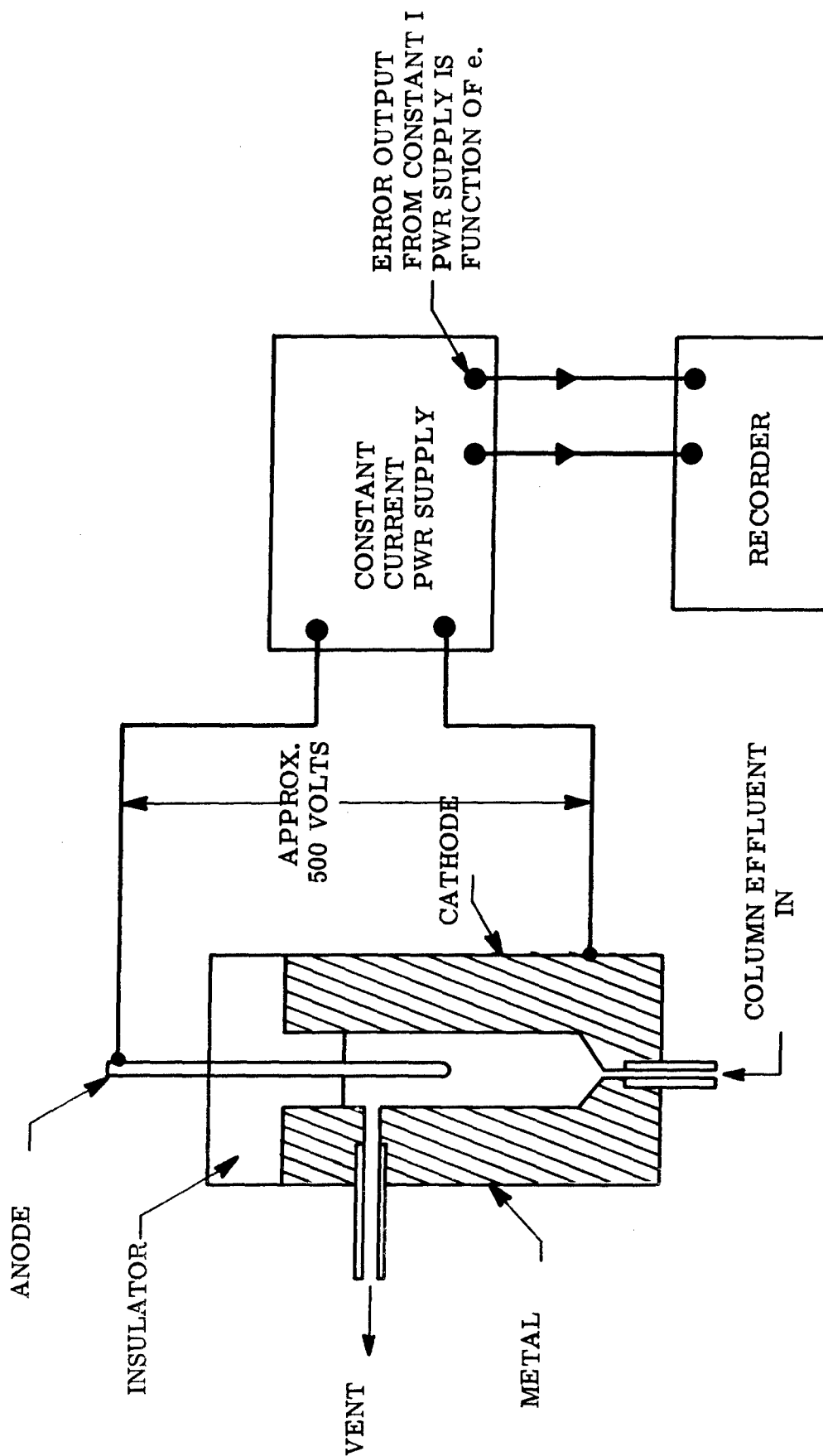


Figure 5 . Karmen Glow Discharge Detector

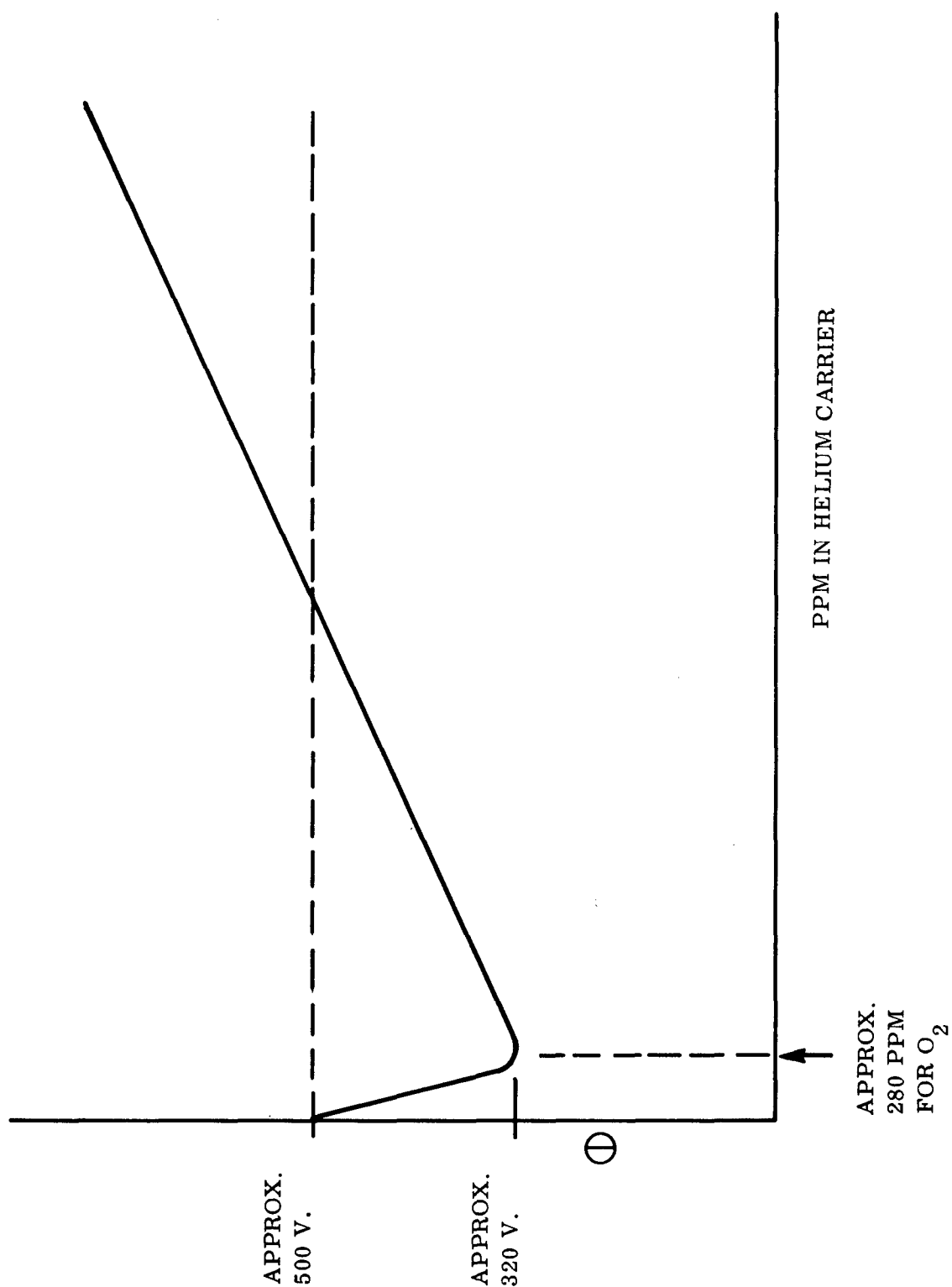


Figure 6. Biphasic Characteristic of Karmen Detector

Condensation Nuclei Gas Analyzer. A relatively unknown toxic gas analyzer technique is the concept of Condensation Nuclei detection. For certain toxic contaminants this detector is now operational, being marketed by General Electric for the detection of hydrazine and other toxic substances (Ref. 22). Figure 7 shows the basic Condensation Nuclei Gas Analyzer. Some typical concentration sensitivities for the condensation nuclei type gas analyzer are shown in Table 20, (Ref. 23).

TABLE 20
CONDENSATION NUCLEI GAS ANALYZER DETECTION SENSITIVITY

Substance	Minimum Concentration, ppm	TLV ⁽¹⁾
Carbon Monoxide	1.0	100.
Methyl Mercaptan	0.01	50.
Mercury (vapor)	0.001	0.1
Nitrogen Dioxide	0.5	5.
Sulfur Dioxide	0.001	5.

(1) ACGIH Threshold Limit Values for 1962

The gas mixture to be analyzed is passed first through a particle filter to remove any ambient nuclei present in the sample (in practice down to less than 50 particles per cc.). It then is passed through a reaction section where the specific gas or group of gases of interest are converted to an aerosol by one of a number of photochemical, chemical or thermal processes. This aerosol, consisting of fine particles which can act as condensation nuclei, together with the remaining gas constituents, are then passed through a humidifier to achieve a 100% relative humidity condition. The humidified mixture then flows through the first section of a rotary motor driven valve into the expansion chamber. After a brief dwell period, the second section of the rotary valve opens, exposing the expansion chamber to a source of regulated vacuum. The sudden expansion results in adiabatic cooling of the gas sample causing the relative humidity to rise above 100%. The water vapor will then condense out on any nuclei present. The resulting droplets soon grow in size to where they can scatter light. The expansion chamber contains a dark-field optical system which delivers no light to the photomultiplier tube in the absence of fog droplets. With droplets present in the chamber, light is caused to be scattered to the photomultiplier. The amount of light received is proportional to the number of droplets (each one containing a nucleus), and to their scattering area.

One disadvantage of a condensation nuclei type instrument used for gas analysis is the inherent selectivity. A condensation nuclei instrument can only detect and identify the specific gas (or group of gases) for which it is designed. Thus, as with the gas chromatograph, detection and/or identification of unanticipated gas constituents cannot be accomplished. If specific identification is not required, conversion of all contaminants in the atmosphere sample to condensation nuclei is a possible alternative. This concept has been explored to some degree (Ref. 23) with promising results obtained. This can result in a highly sensitive instrument which will be sensitive to total contaminant concentration. With consequent simplification of the instrumentation, it becomes a consideration for application to spacecraft.

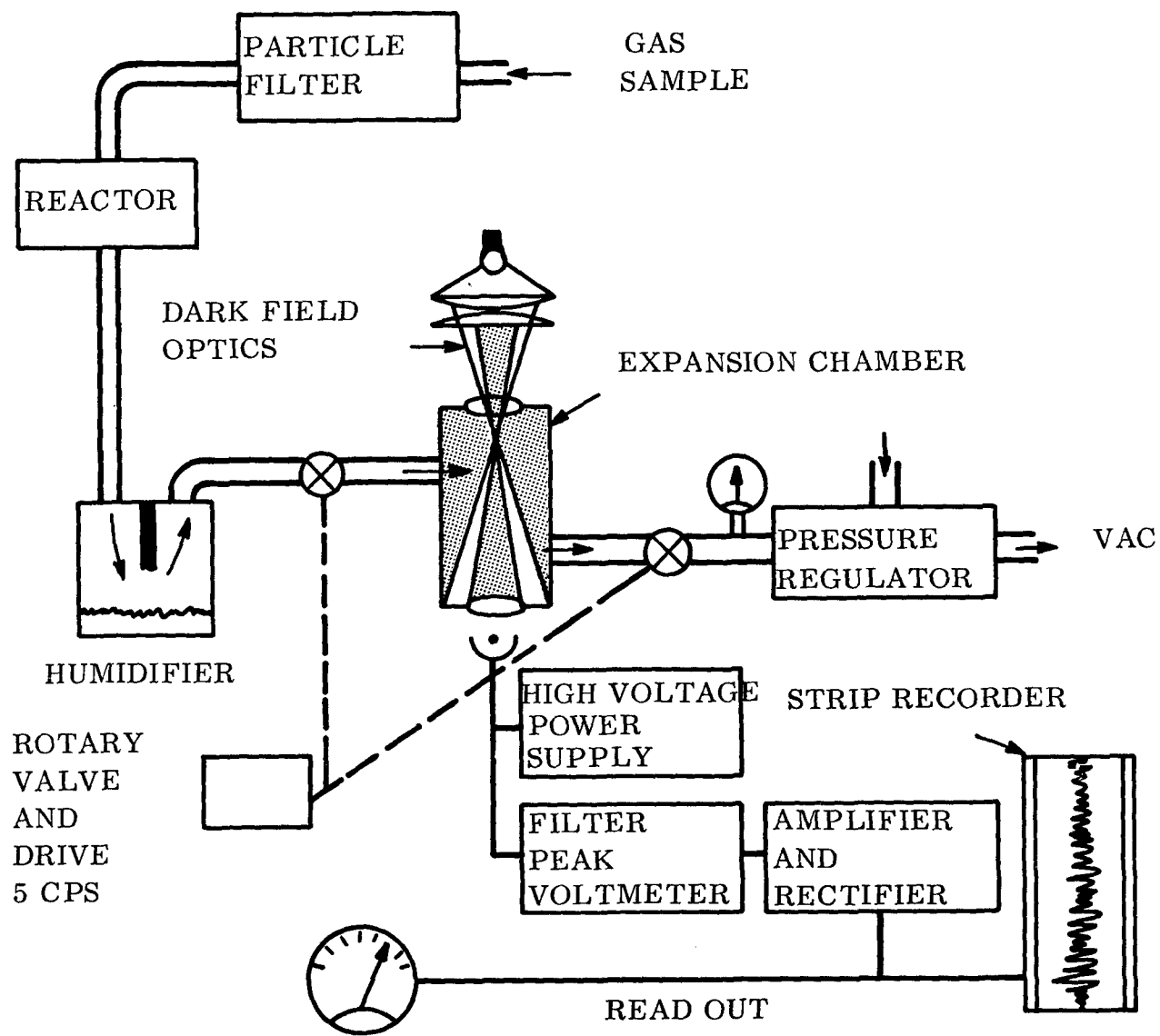


Figure 7. Condensation Nuclei Gas Analyzer Schematic

Multiple Gas Instrument Combinations. When two or more analytical instruments are combined during the analysis of a given gas mixture, it is obvious that greater accuracies from both a qualitative and quantitative standpoint can be achieved, especially when positive detection and identification of a given toxic contaminant is desired. Probably the most powerful combination in the state of the art today is the gas chromatograph and mass spectrometer (Ref. 24). While these instruments by themselves are powerful multiple-gas analytical instruments, they both possess certain disadvantages. For example, the gas chromatograph requires a column which has been specifically designed to separate the gases of a specific gas mixture. It is often extremely difficult to design a column complex to separate in time, one or more of the specific gases from a complex multi-gas mixture. Present state of the art detectors used as part of gas chromatographs have combinations of desirable and undesirable characteristics as previously discussed. A major disadvantage when using the gas chromatograph alone, regardless of the form of detector, is the possibility that it will fail to identify a gas for which the chromatograph column has not been designed, since the instrument does not identify gases by a fundamental property as does the mass spectrometer. The major advantages of the gas chromatograph lie in its ability to physically separate a gas mixture, and, when using ionization detectors specific to certain groups of gases, to detect down to parts per billion.

The mass spectrometer, on the other hand, when analyzing a gas mixture, displays spectra for all gases in the mixture simultaneously. This can cause overlapping of the gas spectra and therefore make it difficult to determine whether a given spectral peak is a cracked product of one gas or another. Its major advantage lies in its ability to identify a given gas by a fundamental characteristic of the gas; the molecular weight to charge ratio.

Combining these two instruments can thus be seen to form a powerful tool for gas analysis. In such an arrangement, the mass spectrometer becomes an extremely versatile, high-resolution, identifying detector for the gas chromatograph. However, the present dependable sensitivity is no better than about 100 parts per million for a unit packaged for spacecraft use.

Concentration and Separation. Concentration and separation in one form or another has been a widely used technique for supplementing detection and identification instrumentation for detecting trace gases at very low concentration levels. In mass spectroscopy, for example, the spectra of high concentration gases (such as oxygen and nitrogen) and low concentration gases (such as some of the toxic contaminants) can overlap. Thus critical toxic contaminants of low concentration can be masked. Also the sensitivity of a mass spectrometer designed for space use cannot reliably be expected to exceed about 100 parts per million. Separation and concentration techniques can improve the effective sensitivity of the mass spectrometer down to well below the one part per million range. Freeze-out is commonly used in mass spectroscopy for separating condensables from non-condensables in order to minimize masking. Southwest Research Institute (Ref. 25) employed various physical and chemical techniques to separate and concentrate metabolic trace constituents from some 60 liters of expired air. Gas concentrations as low as 0.0001 ppm (referenced to the original volume) were detected. Flight type hardware for trace gas concentration and separation does not presently exist; no great difficulty is anticipated in adapting laboratory concentration methods for spacecraft applications.

Separation and concentration techniques are not limited to use in mass spectroscopy. These techniques are equally useful in conjunction with spectrophotometers and condensation nuclei type instruments. A gas chromatograph inherently provides separation; however, concentration is still a useful tool to provide for detection and identification of gases in the less than one part per million range.

Instrument Comparison Table. Table 21 summarizes the capabilities of the various gas analytical instrumentation discussed in this study. Reference to this table can allow rapid comparison and selection of the multiple gas instrumentation required for a specific mission.

Specific Gas Instruments

For missions too short to justify complex instrumentation or as an emergency back-up gas sampling system for longer missions, specific gas detection for a few of the most important toxic gases may be of value. At the present time there are available from several manufacturers, relatively compact kits containing a basic gas sampling apparatus together with glass tubes containing proper reagents supported on some inert absorbent. By passing a metered volume of gas through such tubes, the concentration of the unknown gas is determined visually by the color change of the reagent as well as by the length of the tube affected by the color change. In many instances, the color change is not very distinct especially when other reactive gases are present. In such cases accuracy of the gas concentration determination may vary considerably and may even lead to completely erroneous results. The errors of gas concentration measurements using such specific gas detector tubes can be considerably decreased by providing the operator reference color standards with which to compare color changes of the reagents. Such color standards are particularly useful in areas of varying illumination and intensity as well as spectral balance.

It has been the experience of the Naval Research Laboratory personnel engaged in chemical research in atmosphere purification and control on nuclear-powered submarines, that thorough training of operators using the gas analysis tubes greatly increased the accuracy of gas concentration determinations (Anderson, W., NRL Personal Communication, November 1962). However, even under most favorable conditions, the accuracy that can be attained with this technique seldom exceeds 20 percent. In many cases the ratio of apparent concentration to true concentration may be in the range from 0.25 to 4.0 (Ref. 26).

In spite of these inadequacies, colorimetric tubes may be found to be useful in spacecraft applications to give at least approximate concentration of toxic gases in the atmosphere.

While many specific colorimetric tubes for a long list of gases have been developed, it is very unlikely that more than about five or six kinds would be needed in a spacecraft, simply because from the detailed knowledge of materials to be used in such a vehicle it will be known a priori that certain gases cannot be present under any circumstances. In addition, a close identification of all the gases is not required. It will be sufficient to identify certain families of toxic gases if present in concentrations near or above the allowable limit. The suggested tubes are:

TABLE 21

COMPARISON OF MULTIPLE-GAS DETECTOR PERFORMANCE CHARACTERISTICS

Instrument	Sensing or Separation Method	Hi gauss Magnetic Fields Required?	Gases Or Types Of Gases Detected	Sensitivity (Dependable)	Specificity	Resolution	Sample Size	Sampling Speed	Quantitative Ability	State of Art	Packaged For Space Flight?
Mass Spectrometer											
1 Magnetic Deflection	Mass to charge	Yes	all to m/e=100	10 to 100 ppm	excellent	excellent	small as 100 cc	2 to 5 minutes	very good	present	yes (Development model only)
2 Time-of-Flight	→	yes	all to m/e=100	10 to 100 ppm	excellent	excellent	→	Up to 10,000 complete spectra per sec.	very good	present	yes (Development model only)
3 High Frequency	→	no	all to m/e=100	10 to 100 ppm	excellent	very good	→	Up to 10 complete spectra per sec.	good	present	no
Gas Chromatograph											
1 Thermal Conductivity Detector	Absorbance & partition delay in a column (1)	no	all	100 to 1000 ppm	very good for specific column (1)	very good for specific column (1)	1 to 5 cc (1)	2 to 15 minutes (1)	excellent	present	no
2 H ₂ flame Ionization Detector	→	no	all organic except formic acid, CO ₂ , and CO. no inorganics. See 3.2.2.2	1 to 10 ppm	→	→	→	→	good	present	no
3 Argon/Ionization Detector	→		most organics plus H ₂ O, NO, NO ₂ , NH ₃ , PH ₃ , BF ₃ , & Others See 3.2.2.3	1 to 10 ppm	→	→	→	→	good	present	no
4 Karmen Detector	→	no	all	1 to 10	→	→	→	→	good	"just about"	yes (Development model only)
Infra-Red	Absorption coefficient of gas	no	Most organics in addition to CO and CO ₂	20 to 100 ppm	very good	very good	100 to 1000 cc	0 to 10 minutes	good	present	no
Condensation Nuclei Detector	Differential No light scattering by water droplets		Total toxic contaminant	0.1 to 10 ppm	N.A.	N.A.	20 cc	5 per second for total contaminant	very good	future (for space)	no

(1) applies to gas chromatograph in general

1. Carbon Monoxide (in the presence of hydrocarbon and nitrous gases).
2. Benzene and other aromatics.
3. Hydrogen sulfide, sulfur dioxide.
4. Chlorine and halides.
5. Ammonia and amines.
6. Hydrogen fluoride.

In addition to the above tubes, a tube for detection of mercury may also be included, should there be a possibility of mercury spillage.

A complete list of available gas detector tubes manufactured by Kitagawa of Japan and Mine Safety Appliance Co. have been compiled in Table 22. The Kitagawa tubes are distributed in this country by Union Industrial Equipment Corporation, Port Chester, New York.

The gas-detector tubes are supplied with a hand operated pump designed to draw air samples at a reproducible, fixed rate through the detector tubes. If no color change in the tube develops after one pump stroke, the procedure is repeated until a color change appears or until such time at which there is assurance that the gas in question is not present at a concentration greater than the minimum detectable value. Thus each analysis can be quite time consuming if the particular gas is absent or present in very low concentration. In order to speed up the analysis, the atmosphere sample may be drawn through tubes arranged in parallel, or still better, drawn through the tubes in sequence. In this manner a complete analysis for about a half dozen gas families can be performed within the time period which may be required for one specific gas existing in low concentration.

Instrumentation Specifications as Basis for Compact Kit

Probably the most important piece of information confirmed during the detection and identification methods portion of this study, is the lack in the present state-of-the-art of a versatile instrument for monitoring toxic gases and vapors. No instrument exists, which exhibits in the same instrument, the sensitivity, specificity, and range of gases detected, required of an instrument for monitoring the spacecraft atmosphere during intermediate range and long range space missions. In the immediate future state-of-the-art, with the advent of the Karmen detector, techniques involving the gas chromatograph appear promising, as does the high frequency type

GAS DETECTOR TUBE

GAS	MEAS. RANGE	MAC	TUBE NO.	SOURCE	INTERFERENCE
Acetone	.05-5%	0.1%	102A	Kitagawa	Organic vapors, H ₂ S SO ₂
Acetylene	3-600 ppm	----	82802	MSA Co.	Hydrocarbons, CO, H ₂ S, NH ₃
Acetylene	50-100 ppm	----	101	Kitagawa	Hydrocarbons, CO, H ₂ S, HCN
Arsine	.05-1 ppm	.05 ppm	87031	MSA Co.	SbH ₃ , PH ₃
Acrylonitrile-- high-range	0.1-3.5%	.002%	128A	Kitagawa	Organic vapors
Acrylonitrile-- low-range	10-500 ppm	20 ppm	128B	Kitagawa	Organic vapors
Ammonia--high- range	1-25%	0.01%	105A	Kitagawa	Organic vapors
Ammonia--low- range	20-700 ppm	100 ppm	105B	Kitagawa	Amines
Arsine	5-160 ppm	.05 ppm	140	Kitagawa	H ₂ S, PH ₃
Benzene	10-310 ppm	25 ppm	118A	Kitagawa	Aromatics
Benzene	10-100 ppm	25 ppm	72986	MSA Co.	Aromatics
Benzene(in pre- sence of aromatics)	25-345 ppm	25 ppm	118B	Kitagawa	Toluene above 500ppm
Bromine	5-75 ppm	0.1 ppm	82399	MSA Co.	H ₂ S, NH ₃ , NO ₂ , C ₂ H ₄ ,
Bromine	5-200 ppm	0.1 ppm	87042	MSA Co.	H ₂ S, NH ₃ , NO ₂ , C ₂ H ₄ ,
Bromine	10-300 ppm	0.1 ppm	114	Kitagawa	Halogens, ozones, nitrous gases
Carbon dioxide	.05-1%	0.5%	85976	MSA Co.	-----
Carbon dioxide -- high range	0.1-2.6%	0.5%	126A	Kitagawa	acid gases at high concentrations
Carbon dioxide -- low-range	300-700 ppm	5000 ppm	126B	Kitagawa	acid gases at high concentrations
Carbon Dioxide L- type	1-20%	0.5%	126L	Kitagawa	acid gases at high concentrations
Carbon Monoxide	.001-0.1%	0.01%	47134	MSA Co.	NO ₂ , C ₂ H ₆ , Hydro-
Carbon Monoxide	25-6000 ppm	100 ppm	106A	Kitagawa	carbons, C ₂ H ₄ , C ₂ H ₂ , nitrous gases, HCN H ₂ S
Carbon Disulfide	10-200 ppm	20 ppm	141	Kitagawa	H ₂ S above 50 ppm, SO ₂ 150 ppm
Carbon Monoxide	25-6000 ppm	100 ppm	106B	Kitagawa	Hydrocarbons, C ₂ H ₂ , H ₂ S, HCN, Nitrous gases
Carbon Monoxide	25-600 ppm	100 ppm	106C	Kitagawa	C ₂ H ₂ , HCN
Chlorine	0.5-20 ppm	1 ppm	82399	MSA Co.	Halides
Chlorine	3-100 ppm	1 ppm	87042	MSA Co.	Halides

TABLE 22 (CONTINUED)
GAS DETECTOR TUBES

GAS	MEAS. RANGE	MAC	TUBE NO.	SOURCE	INTERFERENCE
Chlorine	1-40 ppm	1 ppm	109	Kitagawa	Halogens, O ₂ , nitrous gases
Chlorine Dioxide	10-500 ppm	0.1 ppm	116	Kitagawa	Halogens, O ₂ , nitrous gases
Chlorobenzene	10-200 ppm	75 ppm	85834	MSA Co.	Halogens, halides
Carbon Tetra- chloride	5-300 ppm	25 ppm	147	Kitagawa	CO, CL ₂
Cyclohexane	100-6000 ppm	400 ppm	115	Kitagawa	Organic vapors
Decaborane	0.01-1 ppm	.05 ppm	82099	MSA Co.	Hydrazine, UDMH, H ₂ S
Diborane	0.1-3 ppm	0.1 ppm	82099	MSA Co.	Hydrazine, UDMH, H ₂ S
O-dichloro- benzene	10-200 ppm	50 ppm	85834	MSA Co.	Halogens, halides
cis-1,2 dich- lorethylene	25-400 ppm	200 ppm	85833	MSA Co.	Halogens, halides
diethyl ether	400-1400 ppm	400 ppm	107	Kitagawa	Organic vapors
Dimethyl ether	100-1,200, 000	50 ppm	123	Kitagawa	Organic vapors
Ethanol	0.04%-5%	0.1%	104A	Kitagawa	Organic vapors, H ₂ S, SO ₂
Ethyl bromide	25-400 ppm	200 ppm	85833	MSA Co.	halogens, halides
Ethyl chloride	100-2000	1000	85833	MSA Co.	halogens, halides
Ethylene	0.5-100 ppm	----	108B	Kitagawa	CO, C ₂ H ₄ , H ₂ S, HCN
Ethylene	0.5-100 ppm	----	82802	MSA Co.	CO, NH ₃ , H ₂ S, hydrocarbons
Ethylene oxide	0.01-3.5%	0.05%	122	Kitagawa	Organic vapors, H ₂ S SO ₂
Hexane	0.01-0.6%	.05%	113	Kitagawa	Organic vapors
Hydrazine	0.5-20 ppm	1 ppm	87492	MSA Co.	-----
Hydrogen Cyanide	2-50 ppm	10 ppm	73497	MSA Co.	NH ₃ , H ₂ S
Hydrogen Cyanide	0.01-3%	.001	112A	Kitagawa	Cyanogen, H ₂ S, SO ₂
Hydrogen Fluoride	0.5-5.0 ppm	3 ppm	8123	Kitagawa	-----
Hydrogen Sulfide-- high-range	0.01-0.17%	0.002%	120A	Kitagawa	SO ₂
Hydrogen Sulfide-- low-range	5-160 ppm	20 ppm	120B	Kitagawa	SO ₂
Hydrogen Sulfide	1-800 ppm	20 ppm	87414	MSA Co.	SO ₂
Hydrogen Sulfide in presence of SO ₂	.005-0.16%	.002%	120C	Kitagawa	HC, CO, Nitrous gas, HCN
Mercury	0.05-2 mg/m ³	0.1 mg/m ³	83089	MSA Co.	-----
Mercury	0.1-2 mg/m ³	0.1 mg/m ³	142	Kitagawa	CL ₂ , NO ₂
Methanol	0.01-6%	0.02%	119	Kitagawa	Organic vapors, H ₂ S, SO ₂
Methyl bromide	10-500 ppm	20 ppm	157	Kitagawa	halogens, nitrous gases
Methyl bromide	10-100 ppm	20 ppm	85834	MSA Co.	halogens, halides
Methyl Ethyl Ketone	0.01-1.4%	0.02%	139B	Kitagawa	Organic vapors
Nickel carbonyl	20-700 ppm	0.001 ppm	129	Kitagawa	H ₂ S, SO ₂
Nitrogen Dioxide	0.1-50 ppm	5 ppm	84099	MSA Co.	H ₂ S, halides
Nitrogen Dioxide	1-1000 ppm	5 ppm	117	Kitagawa	halogens, O ₂ , N ₂ O ₅

TABLE 22 (CONTINUED)
GAS DETECTOR TUBES

GAS	MEAS. RANGE	MAC	TUBE NO.	SOURCE	INTERFERENCE
Pentaborane	0.01-1 ppm	.005 ppm	82099	MSA Co.	Hydrazine, UDMH, H ₂ S
Perchloroethylene	10-300 ppm	100 ppm	85833	MSA Co.	Halogens, halides
Phosphine--high range	20-800 ppm	0.05 ppm	121A	Kitagawa	H ₂ S, As H ₃
Phosphine--low range	5-90 ppm	0.05 ppm	121B	Kitagawa	H ₂ S, As H ₃
Propylene	1-400 ppm	----	82802	MSA Co.	NH ₃ , H ₂ S, CO, HC
Sulfur dioxide	1-50 ppm	5 ppm	74354	MSA Co.	H ₂ S, NH ₃ , Cl ₂
Sulfur dioxide-- middle-range	0.04-.3%	5 ppm	103B	Kitagawa	H ₂ S
Sulfur Dioxide-- low-range	5-300 ppm	5 ppm	103C	Kitagawa	H ₂ S
Sulfur Dioxide-- D-type	1-80 ppm	5 ppm	103D	Kitagawa	H ₂ S
Toluene	1-1000 ppm	200 ppm	124	Kitagawa	Aromatics
Toluene	5-400 ppm	200 ppm	72986	MSA Co.	Aromatics
Trichloroethylene	25-600 ppm	100 ppm	85833	MSA Co.	Halogens, halides
Trichloroethylene (perchloroethylene)	10-400 ppm	100 ppm	134	Kitagawa	Halogens, halides O ₃ , nitrous gases -----
UDMH	0.5-10 ppm	----	81977	MSA Co.	
Xylene	10-400 ppm	200 ppm	72986	MSA Co.	Aromatics

mass spectrometer in combination with a trace gas separation and concentration technique. A long range look at the future state-of-the-art of multiple gas detection instruments indicates promise in the General Electric Condensation Nuclei type instrumentation. The amperometric technique may also be useful to measure total contaminant concentrations.

Materials in use and being considered for use in spacecraft, under both predicted and unpredicted stresses of space flight, can be expected to off-gas numerous toxic contaminants. In the ideal case where none of the materials used in the spacecraft are those which might off-gas toxic contaminants, there would still exist, as a minimum, the off-gassed products of metabolism from the man himself. Therefore assuming a leak-tight spacecraft, numerous toxic contaminants could build up to unacceptable concentrations in a relatively short time (assuming partial or complete failure of the contaminant control equipment). Thus monitoring by gas analytical instrumentation which possess the necessary resolution and sensitivity is required. To cover any eventuality, all missions in excess of a few days duration would include on-board gas analytical instrumentation exhibiting the following performance capabilities:

a. Resolution

Resolve toxic contaminants in the presence of the normal gases (oxygen, diluent and water vapor) which exist in the spacecraft breathing atmosphere. As noted above, a minimum spectrum of toxic contaminants is that generated by the man himself. Table 1 lists these constituents.

b. Sensitivity

Exhibit a sensitivity high enough to discern above the instrument background noise the threshold concentration of any toxic gas or gases expected. This threshold concentration should be an order of magnitude below the unacceptable level for the particular gas involved. A threshold sensitivity of 0.01 ppm appears desirable.

c. Fundamental Mode of Analysis

The method of analysis should allow the identification of gases which may be unpredicted.

d. Sampling Rate

The time from one analysis to the next should be short enough (between 0.1 to 5 min.) to safely monitor the possible rapid build-up of contaminants. In the event the spacecraft environmental control system functions are being operated directly from this instrumentation, the time must be short enough (between 0.01 and 5 seconds) to maintain the stability of the control system and supply the necessary information rate.

e. Sample Flow

The sample flow must be small enough to minimize loss of spacecraft atmosphere (where the analytical technique destroys the sample or discards it outside the vehicle).

f. Fail Safe Characteristics

The instrumentation must indicate in some way when its data are no longer valid.

g. Signal Output Characteristics

The output of the instrumentation must be capable of modulating telemetry signals as well as operate on-board readouts.

h. Reliability

The mean-time-to-failure of the instrumentation including redundancy effects must be consistent with the mission length.

i. Accuracy

Plus or minus 10% of full scale.

j. Environmental Conditions

The instrumentation must be capable of meeting the performance requirements when subjected to the following environmental conditions or rational combination thereof:

<u>Environment</u>	<u>Range</u>
Temperature	0 to 150°F
Pressure	ambient to vacuum
Radiation	5 REM max. normal, 100 REM max. emergency
Humidity	0 to 100% RH
Acoustics	135 db between 40 and 9600 cps
Acceleration	20 g along each of three mutually perpendicular axes
Vibration	±2.3 g's, 20 to 50 cps 0.018 in. double amplitude; 50-112 cps 11.4 g's; 112-2000 cps (along each of three mutually perpendicular axes).
Impact Shock	20 g's for 10 milliseconds along each of three mutually perpendicular axes.

The selection of actual instrumentation to identify and detect toxic contaminants will depend on mission type and duration. This is illustrated below for assumed mission type and duration.

a. Short Missions

Short missions may be defined as earth orbiting flights or the equivalent of durations up to several days. Because of the short period, toxic gas monitoring instrumentation no more complicated than several of the specific single-gas detectors previously described will be required. The specific single-gas detector chosen for a particular short mission will depend on data

developed during spacecraft design and ground testing, the results of which will permit prediction of those gases which will require monitoring. Note that in Project Mercury, the high permissible leak rate from the capsule negates any requirement for toxic gas monitoring.

b. Intermediate Missions

Flights in the intermediate range category may be defined as earth orbital flights of duration up to several weeks and/or lunar voyages. Toxic gas monitoring instrumentation for this class of mission will be more complicated, consisting of a multiple gas analysis instrument such as a gas chromatograph plus back-up specific single gas detectors for predicted, problem gases. The relative short duration mission will permit extensive ground testing prior to flight.

c. Long Missions

Extended range missions, defined as inter-planetary voyages and manned space station occupancy of durations up to a year and more, will require multiple gas analysis instruments capable of detecting a wide range of gases and vapors, many of which may not be predictable by ground testing or even past mission data. This requirement would most certainly point to an instrument, such as the mass spectrometer in series with a trace gas separation and concentration technique wherein detection and identification depends on a fundamental characteristic of the particular gas or vapor.

PARTICULATE CONTAMINANTS

As for gases and vapors, the detection and identification methods employed for particulate contaminants for a specific spacecraft will depend to a large extent on the type and duration of the mission. Also, and in particular for long duration missions wherein prior ground testing may not be 100% effective, the generation of particulate contaminants, both anticipated and unanticipated, must be assumed. For spacecraft use, instrumentation must be provided to determine both concentration, in terms of total number and/or weight of particles within the critical size range, and the chemical composition. Both are required to determine whether or not particulate contaminants are within tolerable limits.

Instrumentation

Tolerable limits for particulate contaminants are listed by the ACGIH (Ref. 18) in terms of both milligrams per cubic meter and millions of particles per cubic foot (based on impinger samples counted by light-field techniques). Thus metallic dusts and fumes are reported in terms of weight concentration; however the error in appraisal of hazard may be considerable because of coarse particles in the sample. On the other hand, mineral dust is reported in terms of number of particles. This latter practice does not compensate for differences in size within the hygienic range below 5 micron. Equal number concentrations of one and three micron size particles will not represent the same degree of hazard because of differences in alveolar

deposition and in basic toxicity. Conversion from one to the other requires a knowledge of both particle size and particle density.

Detection. Many techniques have been devised for determination of atmosphere particulate concentration for both laboratory and field use. These sampling instruments may be categorized according to collection mode as follows: settlement, both gravity and centrifugal; filtration; impingement; and precipitation (Ref. 27). In general particles are collected on slides or the equivalent with concentration for a given size range of particles determined by a combination of microscopy, gravimetric, and chemical techniques. Electric and thermal precipitators and various filter media are superior to impingement type relative to collection efficiency for the complete particle size range of interest. The molecular or membrane filter and thermal precipitator have the added advantage of depositing particles without physical alteration and in such a manner as to permit direct microscopic examination without disturbing the particles. By making particle size measurements on the collected sample along with the particle count, concentrations may be reported for each size increment, thus greatly increasing understanding of the nature of the contaminant exposure. In contrast, impingement-type instruments (used exclusively in the U. S. Public Health service as a basis for determining tolerable exposure limits) have low absolute collecting efficiency for particles smaller than one micron. Also disaggregation and shattering of particles occurs to various extents in impingement type devices, further clouding the actual particle size distribution. In addition to optical microscopy, size distribution may be determined by elutriation or electronic microscopy. Electron microscopy offers an order of magnitude improvement in minimum particle size measurement, the limit of resolution for the optical microscope being about 0.4 microns.

In general, sampling rate is dependent upon the physical limitations of the instrumentation employed rather than upon any physiological reasons. A relatively rapid sampling rate has the advantage of providing both trend information and, by integration, longer term averages. The importance of sampling rate depends on the type and weight rate of contaminant release. Silicosis requires prolonged (many year) exposure, whereas lead intoxication may develop after a few months. Poisoning from cadmium fumes or a toxic organic dust may result in a few hours.

Dusts and smoke can be visually observed when present in high concentrations. Harmful materials of low toxicity, such as zinc oxide, are readily visible under favorable conditions. However, concentrations on the order of 1 mg per cubic meter (well above the safe limits for cadmium and lead) are not easily observed.

For automatic type instrumentation, a continuous indication of particle count and size distribution may be obtained using detectors employing a light scattering technique. The Rayco photometer, using a dark field optical system, in combination with a gated counter can determine the number of particles ranging from 8 to 0.2 microns in diameter in a number of discrete size steps. Accuracy is somewhat better for relative than for absolute number; performance degrades if the total number of particles becomes too large. Similarly, an aerosol, smoke and dust photometer manufactured by Phoenix Instrument Co. provides a count of total particles of significant size.

Condensation nuclei type instruments (described in section 3.1.1.4) may also be used to automatically and continually determine the presence of particulate matter. Particles ranging in size from 0.1 to 0.001 micron in diameter are readily detected using this technique (Ref. 23). However, because of the mode of operation, only the total quantity of particles is determined, regardless of particle size distribution. Total counts as low as 10 particles per cubic centimeter can be obtained. A sampling rate of several times per second results in essentially a continuous measurement of particulate concentration. Figure 8 shows schematically the condensation nuclei type instrument when used as a particulate detector and counter. In any one cycle, the incoming sample containing the particulate matter is drawn in through a humidifier whose purpose is to bring the sample to a 100% relative humidity condition. It is then valved into the expansion chamber where after a brief dwell period the sample is expanded rapidly to a source of regulated vacuum. The sudden expansion results in adiabatic cooling of the sample and causes the relative humidity to rise above 100%. Water will then condense on the particulate matter present. The resulting droplets soon grow to a size where they can scatter light. Also contained in the expansion chamber is a dark field optical system which produces no light to the photomultiplier phototube in the absence of condensation nuclei droplets. However, with droplets present in the chamber, light will be scattered to the phototube. The intensity of light is proportional to the number of droplets (each containing one nucleus) and to their scattering area. The output of the photomultiplier tube, after amplification, can be applied to telemetry and/or recorders. As a matter of interest, airborne bacteria can be differentiated from other particulate matter and counted using the condensation nuclei technique.

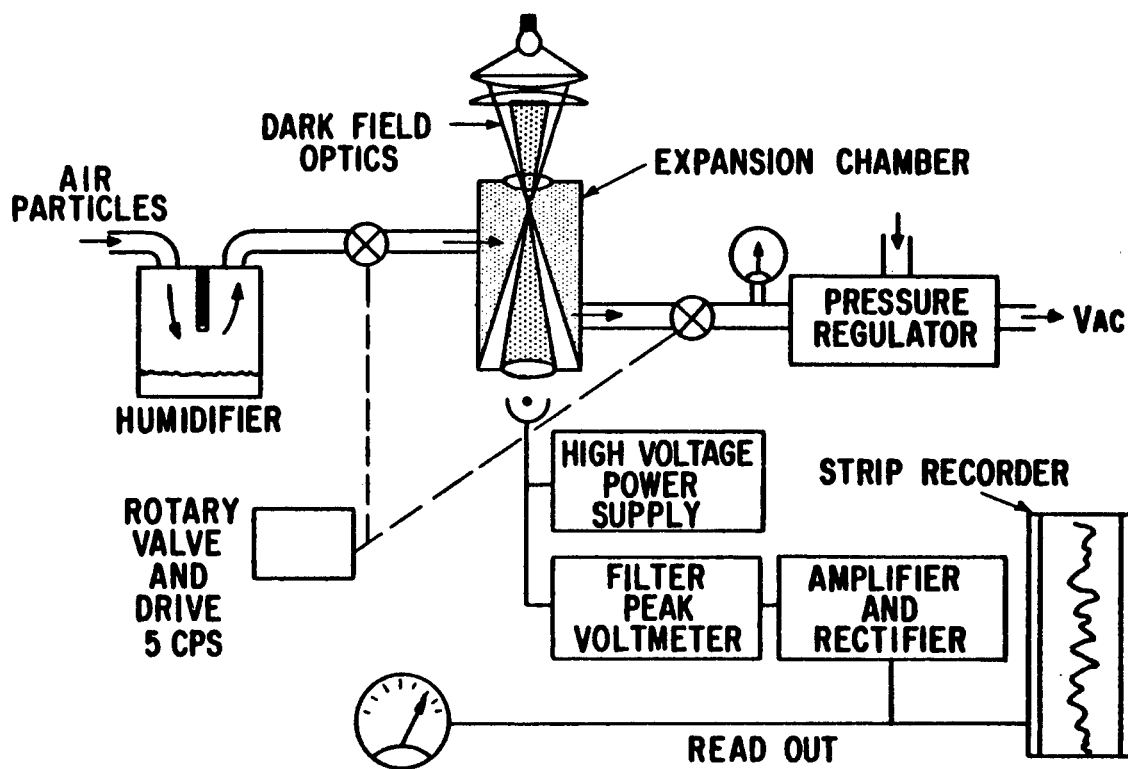


Figure 8. Condensation Nuclei Particle Detector

Identification. Quantitative identification of particulate contaminants may be accomplished by chemical analysis, petrographic analysis, immersion, differential fusion, X-ray diffraction, and combinations thereof. For example, the best method for the determination of free silica (an unlikely problem in spacecraft) requires standard chemical analyses combined with petrographic and X-ray diffraction analyses of residues at various steps in the procedure (Ref. 28). A sample size of 0.1 gm or less may be used. Petrographic, immersion, and differential fusion may be used for mineral dust analysis. X-ray diffraction may be used advantageously for the analysis of a particle mixture which may contain both metallic and non-metallic substances. Quantitative estimates of the amount of each substance present may be obtained. In combination with a recording geiger counter, the X-ray spectrophotometer can provide high accuracy for identifying crystalline type materials (Ref. 29). About a 60 mg sample is required. An electric arc type spectrophotometer also may be used for analysis. Semi-quantitative results can be obtained from samples as small as 0.05 mg. The electric arc type is advantageous for multiple compound identification in that the basic elements of the sample are disclosed; thus there are no restrictions on the kind of sample which may be analyzed. None of the above lend themselves to automated monitoring on a continuous basis.

Instrumentation Specifications

Many of the comments on instrumentation for detecting and identifying gas and vapor contaminants also apply to instrumentation associated with particulate matter. The problem is complicated by the need to measure particle size, particle concentration in terms of weight or in terms of numbers (ideally as a function of particle size), and particle chemical composition per se. All of the foregoing are needed to provide a reliable assessment of the toxic hazard. No single instrument, either currently available or under development, can perform the required functions needed for detection and identification for the entire range of anticipated particle contaminants. Until new techniques are developed, an interim solution combining a particle counting type device, a sample gathering technique and a multi-compound identification capability is suggested. In this combination, a light scattering type photometer and counter combination would function as an early warning device by indicating that the total atmosphere particle count had exceeded the normal (and acceptable) background count. The sampling and identification capability (an impinger type device plus an electric arc type spectrophotometer for example) would then be employed to assess the probable danger of the increased particle count. By setting the automatic warning capability to initiate an alarm when minimum tolerable limits are exceeded, sufficient time should be available to accomplish the relatively time consuming sampling and identification.

One problem associated with the above approach (and probably any other, for that matter) is the determination of an acceptable threshold particle count. Particle inhalation is the usual cause of disability. Particles of 15 to 25 micron size are likely to be caught in the nasal passages or at the back of the throat. Smaller particles may impinge on the trachea or bronchi and gradually be removed by action of the cilia. Particles below five microns in size, and particularly below one micron, may enter and be retained by the alveoli where they may pass directly or indirectly into the lymph circulation. The optimum silica particle size for alveolar deposition is about one micron; for lead (on the basis of density) the optimum size would be about

0.5 micron (Ref. 27). The above would indicate that a count of all particles between approximately 5 and 0.1 micron would be a satisfactory criterion. It might be argued that the high retention of very small particles revealed by the use of the condensation nuclei type instrument, 80% retention at 0.06 micron average radius (Van Luik, F.W. Per. Comm., G.E. (1963), negates the above. However, inspection of Figure 9 reveals the large quantity of smaller particles required to be equivalent (in volume or weight) to a one micron particle. Since mass as well as number is important, the five to 0.1 micron range appears to be satisfactory.

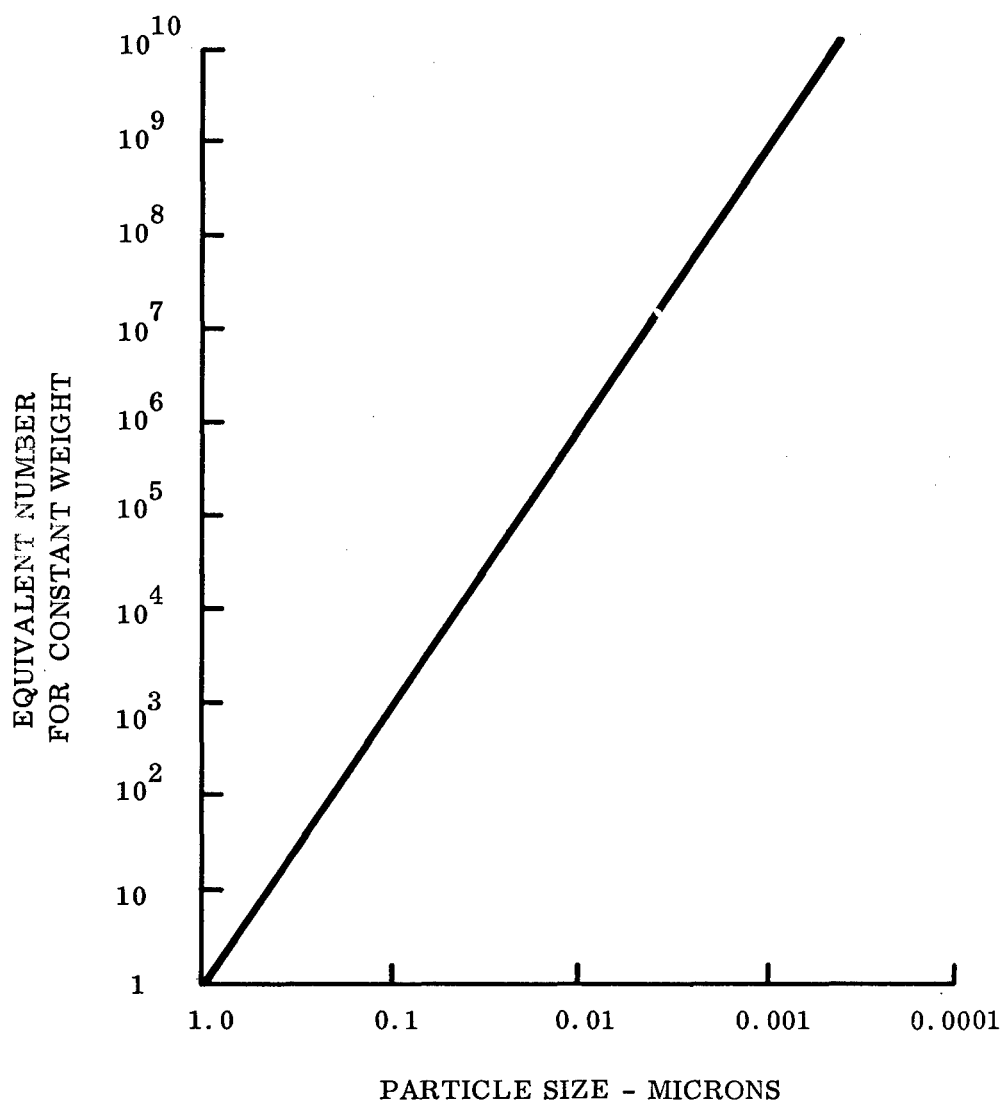


Figure 9. Equivalent Number of Particles

Assuming a leak-tight spacecraft, numerous toxic particulate contaminants could build up to unacceptable concentration levels (assuming partial or complete failure of the contaminant control equipment). Thus all missions in excess of a few days duration should include a particulate contaminant monitoring and identification system exhibiting the following performance capabilities:

a. Resolution

Resolve toxic particulate contaminants in the presence of the normal gases (oxygen, diluent and water vapor) which exist in the spacecraft breathing atmosphere.

b. Sensitivity

Exhibit a sensitivity high enough to discern above the instrument background noise the threshold concentration (on the basis of particle count and/or weight) of any toxic material expected. This threshold concentration should be an order of magnitude below the unacceptable level for the particular contaminant involved. An instrument system threshold sensitivity of the order of 0.01 mg/m³ with particle sizes between 5 and 0.1 microns appears desirable.

c. Fundamental Mode of Analysis

The method of analysis should allow the identification of particle types which may be unpredicted.

d. Sampling Rate

The time from one analysis to the next should be short enough to safely monitor the possible rapid build-up of contaminants. Thirty to sixty minutes or less appears desirable for completing one detection and identification analysis.

e. Sample Size

The sample size must be small enough to minimize loss of spacecraft atmosphere (where the analytical technique discards it outside the vehicle).

f. Fail Safe Characteristics

The instrumentation must indicate in some way when its data are no longer valid.

g. Signal Output Characteristics

The output of the instrumentation system must be capable of modulating telemetry signals as well as operate on-board readouts.

h. Reliability

The mean-time-to-failure of the instrumentation including redundancy effects must be consistent with the mission length.

i. Accuracy

Plus or minus 10% of full scale.

j. Environmental Conditions

The instrumentation must be capable of meeting the performance requirements when subjected to the following environmental conditions or rational combination thereof:

<u>Environment</u>	<u>Range</u>
Temperature	0 to 150°F
Pressure	ambient to vacuum
Radiation	5 REM max. normal, 100 REM max. emergency
Humidity	0 to 100% RH
Acoustics	135 db between 40 and 9600 cps
Acceleration	20 g along each of three mutually perpendicular axes
Vibration	±2.3 g's, 20 to 50 cps 0.018 in. double amplitude; 50-112 cps 11.4 g's; 112-2000 cps (along each of three mutually perpendicular axes)
Impact Shock	20 g's for 10 milliseconds along each of three mutually perpendicular axes.

DISCUSSION

Preparation of lists of materials presently used or proposed for use in spacecraft construction is in progress, but not yet completed. Data on quantities of materials used or proposed are not available. Steps should be taken to compile these data for current system projects and to insure that such data are compiled in future manned spacecraft programs. The lists in the appendices to this report include, as best as can be determined, approximately one-half of all the materials expected to be used in the habitable portion of Apollo, Mercury, Gemini, and Dyna-Soar spacecraft.

The detection and identification of atmosphere contaminants as generated by mechanical, thermal and other stresses may be categorized into two areas: gases and vapors and airborne particulate matter. For gases and vapors, the most significant generation mechanisms appear to be evaporation and thermal degradation. The study of literature on the thermal degradation of elastomers shows that this area of investigation has been reasonably well covered at temperatures above 200°C. There is, however, a lack of information on off-gassing at ambient temperatures. It should be noted that deductions based on the chemical formula of the material can be very unreliable. A comprehensive study of off-gassing under ambient spacecraft conditions of materials likely to be used in manned spacecraft should be initiated. The study should also include the effects of a pure oxygen atmosphere as well as other non-standard atmospheres that may be proposed in the future. A similar situation exists in the area of radiation degradation of elastomers. Both quantity and rate of generation of off-gassing products should be determined. In addition to providing information for identification and detection, this will permit an assessment of the danger of included specific quantities of a particular compound in a given spacecraft. If the quantity or rate of off-gassing will not exceed tolerable limits for a particular operating environment, then no toxic problem exists for that particular contaminant for a given spacecraft. In contrast to the arbitrary exclusion of any substance which may off-gas toxic contaminants, quantity and rate knowledge permits greater flexibility in equipment design.

No single instrument currently exists which exhibits the versatility and performance characteristics required to serve as a monitor for toxic trace gases and vapors during all missions. The variety of materials planned for use on current spacecraft programs and the degradation products therefrom is imposing. Many of these materials can be eliminated, particularly for missions of relatively short duration, by extensive ground testing of the complete operating system. For long duration missions, it would appear unlikely that the long term interactions of materials, off-gassing products, and environment could be duplicated by ground testing. In any case, man himself is an excellent generator of toxic contaminants. Thus, for other than short missions, monitoring instrumentation must be capable of the detection and identification of a wide variety of toxic contaminants, some of which may not have been anticipated. Threshold sensitivity must also be in the parts per billion rather than in the parts per million range in order to detect and identify contaminants at concentrations significantly below tolerable limits. A multiple gas detector(s) in combination with a trace gas concentration and separation technique appears to be the best

available approach to the instrumentation requirements for long term missions. The type of detector used should be one which can detect the presence of an unexpected contaminant.

Particulate matter may be generated by several mechanisms such as mechanical abrasion and recondensation. Many of the comments on gases and vapors are applicable to particulate matter type contaminants. Information on both quantity and rate of generation are needed to permit a realistic selection of spacecraft materials and contaminant control equipment. For long duration missions, it is unlikely that flight conditions can be duplicated during ground testing to a degree which would insure no unexpected particulate type contaminants during later phases of the mission. Thus, for other than short missions, instrumentation for monitoring of particulate matter type contaminants must be capable of the detection and identification of a wide variety of contaminants, some unexpected, and at concentrations significantly below tolerable limits. No single instrument is available to both detect and identify. Detection may be accomplished on a continuous automatic basis by use of a light scattering type of photometer and counter. Either total particle count or count for discrete sizes over the entire particle size range of hygienic interest can be obtained, the latter providing the best data for assessing the potential toxic hazard. Identification is comparatively complicated. A sampling means must be used to gather a sample of sufficient mass to permit analysis. An electric arc type spectrophotometer may be used to establish the chemical identification of the particles. Since identification is time consuming as compared to detection, a suggested approach is to use the detecting portion of the system as an early warning capability followed by the identification procedure when threshold concentration limits are exceeded.

CONCLUSION

In summary, for long duration missions, the generation of a large variety of toxic contaminants, both predicted and unpredicted, can be assumed. Information on quantity and rate of generation of these contaminants is needed to permit a realistic appraisal of their effect in a particular application. Development of new techniques for the detection and identification of toxic contaminants, gases and vapors and particulate matter, is required if useful contaminant monitoring is to become a practical reality for spacecraft applications.

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APPENDIX A

APOLLO COMMAND MODULE MATERIALS LIST

This is a list of materials which are being considered for the Command Module of the Apollo spacecraft as compiled by the Life Sciences Group of the North American Aviation Corp. The list is estimated to be approximately 50% complete.

APPENDIX A

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Adhesive	Epoxy					Stabilization & Control System	Minneapolis Honeywell, Aero Type 6020A
Adhesive	Epoxy					Stabilization & Control System	Minneapolis Honeywell, Aero Type 6293P
Adhesive	Epoxy					Stabilization & Control System	Minneapolis Honeywell, Aero Type 6020G
Adhesive	Silicone					Stabilization & Control System	Dow Corning Q-30079
Banding Strip						Stabilization & Control System	A. J. Gerrard & Co.
Adhesive	Epoxy-Amine TiO ₂ Filler	Yes	170°F	200°F	225°F	Stabilization & Control System P1, 2:Q1, 2	Minneapolis Honeywell Type 6020M & Minnesota Mining
Adhesive	Epoxy-Amine	Yes	170°F	200°F	350°F	Stabilization & Control System P1, 2:Q1, 2	Minneapolis Honeywell Type 6293G
Adhesive Epoxy Cast Resin	Epoxy-Amine Ca CO ₃ Filler	Yes	170°F	200°F	300°F	Stabilization & Control System P1, 2:Q1, 2	Minneapolis Honeywell, Aero 6020Q, AMS 3740
Adhesive	Epoxy	Yes	170°F	200°F	250°F	Stabilization & Control System P1, 2:Q1, 2	Rubber & Asbestos Corp.

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Adhesive	Nitrile	Yes	170°F	200°F	250°F	Stabilization & Control System P1, 2:Q1, 2	Minnesota Mining
Adhesive	Polyamide	Yes	170°F	200°F	300°F	Stabilization & Control System P1, 2:Q1, 2	
Adhesive	Phenolic Glass	Yes	170°F	200°F	300°F	Stabilization & Control System P1, 2:Q1, 2	
Adhesive	Rubber					Stabilization & Control System	Minnesota Mining EC870
Adhesive						Stabilization & Control System	Minnesota Mining EC847
Adhesive						Stabilization & Control System	Dow Corning 6851A A-4000 ADH
Fluid	Trifluoro- chloroethylene	Yes	170°F	200°F	300°F	Stabilization & Control System P1, 2:Q1, 2	
Primer Coating	Gray Vinyl					Stabilization & Control System	Amercoat Corp. Amercoat 33
Primer Coating	Epoxy Strontium- Chromate	No	170°F	200°F	300°F	Stabilization & Control System P1, 2:Q1, 2	

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Laminate	MIL-P-18177	Yes	170° F	200° F	350° F	Stabilization & Control System P1, 2:Q1, 2	
Laminate	Glass Epoxy					Stabilization & Control System	Formica FF-95
Laminate	Glass Epoxy					Stabilization & Control System	General Electric Texto 11559
Laminate	Glass Epoxy MIL-P-18177					Stabilization & Control System	National Vulcanized Fiber Co. G-11-861
Laminate	Glass Epoxy					Stabilization & Control System	Synthane G-11
Laminate	Nylon Phenol Laminate					Stabilization & Control System	Synthane N-1
Laminate	Glass Epoxy					Stabilization & Control System	Minnesota Mining Lamicond 6096
Enamel	Gray Epoxy					Stabilization & Control System	Glidden SE-7077
Enamel	Black Epoxy					Stabilization & Control System	Glidden 287-B-505
Varnish						Stabilization & Control System	Maas & Waldstein Y 170 A
Enamel	Epoxy Polyamide	No	150° F	180° F		Stabilization & Control System P1, 2:Q1, 2	D. J. Peterson

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Enamel	Epoxy	Yes	170°F	200°F		Stabilization & Control System P1, 2:Q1, 2	
Enamel	Brown Epoxy					Stabilization & Control System	D. J. Peterson Poly-EP color 30279
Enamel	Brown Epoxy					Stabilization & Control System	D. J. Peterson Poly-EP Color 30450
Enamel	Gray Wrinkle					Stabilization & Control System	Glidden RGL-212900
Enamel	Gray Wrinkle					Stabilization & Control System	Glidden MGL-9577
Enamel	Black Wrinkle					Stabilization & Control System	Glidden RGL-2-1204
Laminate	Glass Epoxy					Stabilization & Control System	Continental Diamond Co. GB-28-E-FR
Glass	Copper Clad Glass Epoxy	No	150°F	180°F	350°F	Stabilization & Control System P1, 2:Q1, 2	National Vulcanized Fiber Co. G-11-861-1
Glass	Copper Clad Glass Epoxy	No	150°F	180°F	350°F	Stabilization & Control System P1, 2:Q1, 2	Synthane G-11

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION 'COORD)	MANUFACTURER & TRADE NAME
Glass	Acrylic Resin Fiberglass MIL-I-3190B					Stabilization & Control System	Class BA1
Tubing	Fiberglass Vinyl					Stabilization & Control System	Varflex Corp. Varflow 121
Paper (Ungummed)						Stabilization & Control System	Stevens Paper Mills
Paper (Crepe)	MIL-I-15126					Stabilization & Control System	Minnesota Mining 38
Electrical Paper Tape	MIL-I-15126					Stabilization & Control System	Minnesota Mining 3
Tape	Polyester					Stabilization & Control System	Minnesota Mining 56
Tape	Polyester					Stabilization & Control System	Minnesota Mining 5
Tape	Polyester					Stabilization & Control System	Permaccel EE 3504
Felt						Stabilization & Control System	Western Felt
Film	Polyester	No	150°F	180°F	300°F	Stabilization & Control System P1, 2; Q1, 2	Dupont Mylar
Potting & Sealing Compound	Epoxy					Stabilization & Control System	Minneapolis Honeywell, Aero 6020W

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Potting Compound	Epoxy-Amine Urethane	Yes	170°F	200°F	325°F	Stabilization & Control System P1, 2:Q1, 2	Minneapolis Honeywell, Aero 7083A
Tape	Fiberglass MIL-I-15126					Stabilization & Control System	Minnesota Mining 27 Type GFT
Tape	Cotton					Stabilization & Control System	Prahler Electrical Company
Tape	Acetate Cloth Backing					Stabilization & Control System	Minnesota Mining 28
Tying Cord	Fiberglass					Stabilization & Control System	Varflex Corp.
Tying Cord	Nylon MIL-T-713	Yes	170°F	200°F	250°F	Stabilization & Control System P1, 2:Q1, 2	Linen Thread Co.
Varnish	Epoxy	No	170°F	200°F	300°F	Stabilization & Control System P1, 2:Q1, 2	Minneapolis Honeywell, Aero 7134B D. J. Peterson
Lacquer						Stabilization & Control System	Glidden 6967A
Foam	Epoxy					Stabilization & Control System	Minneapolis Honeywell, Aero 6293C
Foam	Urethane					Stabilization & Control System	Nopco Chemical Co. A-206-R Base

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	MAX. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Foam	Urethane					Stabilization & Control System	Nopco Chemical Co. G 306
Lubricant	Silicone Oil					Stabilization & Control System	General Electric Versilube F 50
Lubricant	Halogenfluoro- Carbon					Stabilization & Control System	Minnesota Mining Kel F No. 1
Grease	MIL-I-8660					Stabilization & Control System	Dow Corning DC4
Molding Compound	Polyamide	Yes	170°F	200°F	300°F	Stabilization & Control System P1, 2:Q1, 2	Dupont ZYT 113 NC 10
Molding Compound	MIL-P-14	Yes	170°F	200°F	400°F	Stabilization & Control System P1, 2:Q1, 2	
Molding Compound	Epoxy-Amine	Yes	170°F	200°F	350°F	Stabilization & Control System P1, 2:Q1, 2	Fiberite
Molding Compound						Stabilization & Control System	Durez
Molding Compound	Polyamide, Black					Stabilization & Control System	Dupont ZYT 101BK-09
Gasket	Neoprene-Cork MIL-G-6183					Stabilization & Control System	Armstrong Cork NC 709

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Insert Paper						Stabilization & Control System	Carpenter Paper Co.
Potting Compound	Urethane					Stabilization & Control System	Minneapolis Honeywell, 3645
Potting Compound	Silicone Rubber					Stabilization & Control System	Dow Corning RTV-501 Silastic
Sealing Compound	MIL-S-8516					Stabilization & Control System	Product Research Co. PR 1201Q
Sealing Compound	MIL-S-8516					Stabilization & Control System	Coast Pro-Seal Pro-Seal 727
Sealing Compound						Stabilization & Control System	Minneapolis Honeywell, Aero 7083C
Sealing Compound	Silicone Rubber					Stabilization & Control System	General Electric RTV-90
Screw Sealants						Stabilization & Control System	American Sealants Loctite Grade A Grade C Grade D
Gasket (Conductive)						Stabilization & Control System	Connecticut Hard Rubber
Silicone Sponge Rubber	AMS 3195					Stabilization & Control System	Connecticut Hard Rubber CLR10470
Fairprene Rubber						Stabilization & Control System	Dupont N5580HA Fairprene

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Silicone Rubber						Stabilization & Control System	Dow Corning SUST S-2007
Fluorinated Rubber	MIL-R-25897					Stabilization & Control System	Minnesota Mining Fluorol
Fluorinated Rubber	MIL-R-25897					Stabilization & Control System	Dupont Viton A
Screening Ink						Stabilization & Control System	Naz Dar Type 5511 Type 802 Type DL112
Screening Ink						Stabilization & Control System	Markem Machine Co. HM 7132
Screening Ink						Stabilization & Control System	General Printing WE Verm 44 WE Yellow 44 WE Yellow 43
Thermoplastic	MIL-P-8184					Stabilization & Control System	Rohm & Haas Plex 55 Acrylic
Thermoplastic	MIL-P-5435B					Stabilization & Control System	Rohm & Haas Plexi II-UVA Acrylic
Rod & Strip	Polyamide					Stabilization & Control System	Polymer Corp. Type ZYT 101
Tying Cord	Polyamide MIL-T-713					Stabilization & Control System	Gudebrod Bros. Style 18 Type P Class 2
Tying Cord	Dacron MIL-F-8261					Stabilization & Control System	Western Fishing Line Co. 50 DOF 16A

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL. TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Leadwire	Teflon MIL-W-16878					Stabilization & Control System	Suprenant Type E
Leadwire	Teflon MIL-W-16878					Stabilization & Control System	Hitemp Wire & Cable Co. Type E
Leadwire	Copper MIL-W-3861	Yes	170°F	200°F		Stabilization & Control System P1, 2:Q 1, 2	QPL 3861
Rod & Bar	Teflon					Stabilization & Control System P1, 2:Q 1, 2	Polymer Corp.
Wire, Teflon Jacketed	Teflon MIL-W-16878					Stabilization & Control System	Suprenant Type E
Wire, Teflon Jacketed	Teflon MIL-W-16878					Stabilization & Control System	Hitemp Wire & Cable Co.
Teflon Sheet	Teflon					Stabilization & Control System	Carmer Indst.
Tubing	Wrap Teflon	Yes	170°F	200°F	500°F	Stabilization & Control System P1, 2:Q1, 2	Hitemp Wire & Cable Co.
Tubing	Wrap Teflon	Yes	170°F	200°F	500°F	Stabilization & Control System P1, 2:Q 1, 2	American Super Temp.
Insulation	Teflon MIL-W-16878					Stabilization & Control System	Suprenant Type EE

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APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Insulation	Teflon MIL-W-16878					Stabilization & Control System	Hitemp Wire & Cable Co. Type EE
Tubing	Extruded Teflon AMS 3654	Yes	170°F	200°F	500°F	Stabilization & Control System	Hitemp Wire & Cable Co. Polymer Corp.
Tubing	Vinyl MIL-I-7444					Stabilization & Control System	Irvington Varnish & Insulator 3022 Natvar Corp.
Tubing	Irradiated Olefin MIL-I-7444					Stabilization & Control System	Ray Chem Ray Clad Thermofit Simi-Rigid
Tubing	Irradiated Olefin AMS 53633	Yes	170°F	200°F	250°F	Stabilization & Control System P1, 2:Q 1, 2	Raychem Ray Clad Thermofit RNF
Teflon & Mylar Insulated Wire	MIL-W-16878					Stabilization & Control System P1, 2:Q 1, 2	Suprenant Surok
Thermoplastic						Stabilization & Control System P1, 2:Q 1, 2	Minnesota Mining Kel-F
Thermoplastic						Stabilization & Control System P1, 2:Q 1, 2	Fluoro-Chem Co. FS Fluorolub
Film	Mylar					Stabilization & Control System P1, 2:Q 1, 2	Insulation Mfg.
Thermoplastic	Polyester AMS 3650					Stabilization & Control System	Carmer Instd. Cadillac Plastic Kel-F

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Thermosetting	Di-Alylphthal MIL-M-19633					Stabilization & Control System	MESA Plastics Type GDI Class 30
Anti-Seize Compound	MIL-A-907B					Stabilization & Control System	Armite Labs Leadplate 250
Aluminum	AMS 4120	Yes	170°F	200°F		Stabilization & Control System P1, 2:Q 1, 2	Alcoa
Aluminum		Yes	170°F	200°F		Stabilization & Control System P1, 2:Q 1, 2	Kaiser Alcoa Reynolds
Aluminum	AMS 4001	Yes	170°F	200°F		Stabilization & Control System P1, 2:Q 1, 2	Alcoa
Aluminum	AMS 4037	Yes	170°F	200°F		Stabilization & Control System P1, 2:Q 1, 2	Alcoa
Alumina						Stabilization & Control System	Minneapolis Honeywell, G. V.
Anodize-Hard Aluminum						Stabilization & Control System	
Anodize-Hard Aluminum						Stabilization & Control System	
Anodize-Blue Dyed Aluminum	MIL-A-8625					Stabilization & Control System	Type II

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Anodize-Blue Dyed Aluminum	MIL-A-8625					Stabilization & Control System	Type II
Anodize Clear Seal Aluminum	MIL-A-8625					Stabilization & Control System	Type II
Anodize Di-Chromate Seal	MIL-A-8625					Stabilization & Control System	Type II
Anodize-Red Dyed Aluminum	MIL-A-8625					Stabilization & Control System	Type II
Aluminum	AMS 4016					Stabilization & Control System	Alcoa
Aluminum	AMS 4025					Stabilization & Control System	Alcoa
Aluminum	AMS 4027					Stabilization & Control System	Alcoa
Aluminum	QQ-A-351					Stabilization & Control System	Alcoa
Anodize-High Temp Resistant Black Dyed Aluminum	MIL-A-8625					Stabilization & Control System	
Anodize Marking	Sulfuric Acid Coating					Stabilization & Control System	Type II
Anodize Brown Dyed Aluminum	MIL-A-8625					Stabilization & Control System	

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Anodize Brown Dyed Aluminum	MIL-A-8625					Stabilization & Control System	
Aluminum	QQ-A-601	No	150°F	180°F		Stabilization & Control System P1, 2: Q 1, 2	Alcoa
Aluminum	QQ-A-601	No	150°F	180°F		Stabilization & Control System P1, 2:Q 1, 2	Alcoa
Aluminum	QQ-A-318	No	150°F	180°F		Stabilization & Control System P1, 2:Q 1, 2	Alcoa
Beryllium Copper	QQ-C-530	Yes	170°F	200°F		Stabilization & Control System P1, 2:Q 1, 2	
Beryllium		Yes	170°F	200°F		Stabilization & Control System P1, 2:Q 1, 2	
Nameplate	Aluminum Metal					Stabilization & Control System	C&H Supply Co. Metal-Cal Alum Mech Fast 020
Nameplate	Aluminum Metal					Stabilization & Control System	C&H Supply Co. Metal-Cal Alum Mech Fast 020
Nameplate	Aluminum Metal					Stabilization & Control System	C&H Supply Co. Metal-Cal Alum Mech Fast 020

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Nameplate						Stabilization & Control System	C&H Supply Co. Metal-Cal, Foil, Adhesive Backing
SN Plate over CU plate						Stabilization & Control System	
Shielding	Tin & Copper					Stabilization & Control System	Belden Co.
Cadmium Plating						Stabilization & Control System	
Solder						Stabilization & Control System	
Solder	60/40 58 core 50/50 60/40					Stabilization & Control System	Kester Solder Co.
Solder	60/40					Stabilization & Control System	Alpha Metals
Solder Flux						Stabilization & Control System	Kester Solder Co.
Steel	Chromium Nickel Iron AMS 5688					Stabilization & Control System	
Steel						Stabilization & Control System	U.S. Steel
Steel	AMS 5640	Yes	170° F	200° F		Stabilization & Control System	Crucible

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Steel	AMS 5610					Stabilization & Control System	Crucible
Steel						Stabilization & Control System	Crucible Comp. 301 Comp. 302 Comp. 304
Steel	QQ-S-763					Stabilization & Control System	Crucible
Steel	QQ-S-766					Stabilization & Control System	Crucible
Steel						Stabilization & Control System	C. A. Roberts
Steel	Chromium Nickel Iron AMS 5688	Yes	170°F	200°F		Stabilization & Control System P1, 2: Q1, 2	
Wire	Steel					Stabilization & Control System	Enterprise Wire Co.
Leadwire	Copper Tin QQ-W-343 Type S	Yes	170°F	200°F		Stabilization & Control System P1, 2: Q1, 2	Warren
Steel	MIL-S-5059	No	150°F	180°F		Stabilization & Control System	Crucible Stainless 88
Steel						Stabilization & Control System	Central Steel & Wire Co.

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Brass	AMS 4505					Stabilization & Control System	Anaconda American Brass
Brass	AMS 4610	Yes	170°F	200°F		Stabilization & Control System P1, 2: Q1, 2	Chase Brass & Copper
Brass (Wire)	QQ-W-321	Yes	170°F	200°F		Stabilization & Control System P1, 2: Q1, 2	
Copper						Stabilization & Control System	Anaconda American Brass
Copper	Copper, Lead	Yes	170°F	200°F		Stabilization & Control System P1, 2: Q1, 2	
Phos Bronze						Stabilization & Control System	Miller & Co.
Magnesium	AMS 4120					Stabilization & Control System	Hitchcock
Magnesium						Stabilization & Control System	Dow Chemical Co.
Resistance Wire	88% Copper	Yes	170°F	200°F	500°F	Stabilization & Control System P1, 2: Q1, 2	W.B. Driner
Magnetwire	Copper, Polyvinyl Acetate MIL-W-583 Class 105 Type T2	Yes	170°F	200°F	221°F	Stabilization & Control System P1, 2: Q1, 2	Rea Magnet Wire Co. QPL 583

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Magnetwire	Nylon, Urethane Copper	Yes	170°F	200°F	268°F	Stabilization & Control System P1, 2: Q1, 2	Phelps Dodge Copper Products Types: T4 B Single Nylese B2 Heavy Nylese
Magnetwire						Stabilization & Control System	Phelps Dodge Copper Products
Magnetwire						Stabilization & Control System	Rea Magnet Wire Co. Types T4 B Single Nylsol B2 Heavy Nylsol L2 Isonel-BF
Magnetwire	Polyester Copper	Yes	170°F	200°F	311°F	Stabilization & Control System P1, 2: Q1, 2	Hitemp Wire & Cable Co. Types: L2- Thermisterl
Magnetwire						Stabilization & Control System	Hitemp Wire & Cable Co. SFX Type K
Magnetwire	Copper, Polyvinyl Acetate	Yes	170°F	200°F	221°F	Stabilization & Control System P1, 2: Q1, 2	Phelps Dodge Copper Products
Magnetwire	Double ML Polyamide Copper	Yes	170°F	200°F	482°F	Stabilization & Control System P1, 2: Q1, 2	Phelps Dodge Hitemp Wire
Magnetwire						Stabilization & Control System	Phelps Dodge Copper Products B3 Nylese
Wire	Nickel					Stabilization & Control System	W. B. Driner Grade A

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL. TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Chrome Treatment	MIL-C-5541					Stabilization & Control System	Amchem Alodine 1200A
Clear Chrome Treatment						Stabilization & Control System	Amchem Alodine 1000L
Dumet						Stabilization & Control System	General Electric
Nickel Iron Alloy	AMS 7705	Yes	170°F	200°F		Stabilization & Control System P1, 2: Q1, 2	
Nickel Iron Alloy		Yes	170°F	200°F		Stabilization & Control System P1, 2: Q1, 2	
Bismuth Tin Alloy		Yes	170°F	200°F	281°F	Stabilization & Control System P1, 2: Q1, 2	
Silver Paste		Yes	170°F	200°F		Stabilization & Control System P1, 2: Q1, 2	Emerson Cumming
Iron		Yes	170°F	200°F		Stabilization & Control System P1, 2: Q1, 2	Armco
Cobalt Iron Alloy		Yes	170°F	200°F		Stabilization & Control System P1, 2: Q1, 2	
Gold Plating						Stabilization & Control System P1, 2: Q1, 2	Minneapolis Honeywell, Boston
Cadmium Plating	QQ-P-416						
Hae % Thin							

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Adhesive	Conductive Epoxy					Telecommunica- tions System	Chromerics 360-18
Adhesive	Conductive Resin	Yes & No	104°F	167°F		Telecommunica- tions System	Chromerics 356-18
Adhesive	One-Part Modified Epoxy Resin	Yes & No	104°F	167°F		Telecommunica- tions System	Minnesota Mining EC 2186
Adhesive	Heat Conductor					Telecommunica- tions System	Chromerics 356-16
Adhesive	Silicone Rubber					Telecommunica- tions System	Dow Corning Corp. RTV-140
Adhesive	Silicone Rubber	Yes & No	104°F	167°F		Telecommunica- tions System	Dow Corning Corp. RTV-731
Ceramo-Plastic		Yes & No	149°F	257°F		Telecommunica- tions System	Mycalex Supremica
Ceramic	High Alumina MIL-I-10					Telecommunica- tions System	Centralab Body 208
Cat-L-Ink		Yes & No	104°F	167°F		Telecommunica- tions System	Atlas Silkscreen Corp.
Anti-Friction	90% Molydisulfide 10% Graphite with Phenolic Resin Binder					Telecommunica- tions System	Electrofilm Inc. 4396
Adhesive	Silicone Rubber	Yes & No	104°F	167°F		Telecommunica- tions System	Dow Corning Corp. RTV-731

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Ceramo-Plastic		Yes & No	149°F	257°F		Telecommunica- tions System	Mycalex Supremica
Ceramic	High Alumina MIL-I-10					Telecommunica- tions System	Centralab Body 208
Cat-L-Ink		Yes & No	104°F	167°F		Telecommunica- tions System	Atlas Silkscreen Corp.
Anti-Friction Coating	90% Molydisulfide 10% Graphite with Phenolic Resin Binder					Telecommunica- tions System	Electrofilm Inc. 4396
Flexibilizer for Hysol 4183	Epoxy	Yes & No	104°F	167°F		Telecommunica- tions System	Dow Chemical Co. Exp. Resin X2673-2
Casting Resin	Epoxy	Yes & No	104°F	167°F		Telecommunica- tions System	Houghton Labs. Hysol 4183 with Hardner 3469
Foam	MIL-C-80872	Yes & No	104°F	167°F		Telecommunica- tions System	Nopco Chemical Co. Lockfoam A206
Glass		Yes & No	149°F	257°F		Telecommunica- tions System	Corning Glass 7940
Highly Thermal Conductive Com- pound for Semi- Conductor	Grease-Like Silicone					Telecommunica- tions System	Dow Corning Corp. C-2-0168
Lubricant	Silicone Fluid	Yes & No	104°F	167°F		Telecommunica- tions System	General Electric Versilube F 50

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Lubricant						Telecommunica- tions System	General Electric Versilube G300
Inorganic Bonded Dry Film Lubricant	Molydisulfide Graphite with Sodium Silicate Binder	Yes & No	104°F	167°F		Telecommunica- tions System	Alpha-Molykote Corp. Molykote X-15
Plastic Laminate	Glass Cloth- Epoxy Resin Binder MIL-P-18177	Yes & No	104°F	167°F		Telecommunica- tions System	Continental Diamond Co. Fiber Flame Retardant G-10
Rubber Like Material	Freeze Resistant Neoprene MIL-A-3005	Yes & No	104°F	167°F		Telecommunica- tions System	Dupont Mylar
Rubber Like Material	Silicone Rubber	Yes & No	104°F	167°F		Telecommunica- tions System	Dow Corning Corp. RTV-521
Rubber Like Material	Silicone Rubber	Yes & No	104°F	167°F		Telecommunica- tions System	Dow Corning Corp. RTV-S-5313 RTV-S-5314 with 50% DC-200 Oil
Silicone Gel	Silicone Resin	Yes & No	104°F	167°F		Telecommunica- tions System	Dow Corning Corp. Sylgard 182
Thermoplastic	Monochlorotri- fluoroethylene MIL-P-55028B					Telecommunica- tions System	Minnesota Mining Kel-F
Thermoplastic	Polyethylene Terephthalate MIL-I-631	Yes & No	104°F	167°F		Telecommunica- tions System	Dupont Mylar

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Thermoplastic	Irradiated Polyolefin					Telecommunica- tions System	Raychem
Thermoplastic	Polyamide	Yes & No	104°F	167°F		Telecommunica- tions System	Dupont Nylon 301
Thermoplastic	Polystyrene MIL-P-77B	Yes & No	104°F	167°F		Telecommunica- tions System	Polypenco Q200.5
Thermoplastic	High Polymer of Tetrafluoroethy- lene MIL-P-19468	Yes & No	104°F	167°F		Telecommunica- tions System	Dupont Teflon
Thermoplastic							
Teflon Jacketed Wire						Telecommunica- tions System	Suprenant 4394000 414900
Nickel Coated Wire	Alloy 63 Nickel Coated	Yes & No	104°F	167°F to 212°F		Telecommunica- tions System	Suprenant No. 26 & Smaller Type Wire
Ceramic	Beryllium Oxide	Yes & No	149°F	257°F		Telecommunica- tions System	National Beryllia Co.
Thermosetting	Diallyl Phthalate Mineral Filled					Telecommunica- tions System	Durez
Thermosetting	Mineral Filled Phenolic MIL-M-14E "Bakelite"					Telecommunica- tions System	Durez

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Thermosetting	Epoxy, Filled 1:1 by Weight with Quartz Diethylam- inopropylamine Catalyst	Yes & No	104°F	167°F		Telecommunica- tions System	Shell Chemical Corp. EPON 828 with Filler Curing Agent A
Steel	302 Stainless QQ-S-763B	Yes & No	104°F	167°F		Telecommunica- tions System	Armco Steel
Steel	17-4PH Stainless	Yes & No	104°F	167°F		Telecommunica- tions System	Armco Steel
Steel	440 Stainless					Telecommunica- tions System	Armco Steel
Aluminum	Aluminum 6061	Yes & No	75°F	252°F		Telecommunica- tions System	Alcoa
Aluminum	Aluminum 5052 QQ-A-318Bb	Yes & No	104°F	167°F		Telecommunica- tions System	Alcoa
Aluminum	Aluminum 2024	Yes & No	104°F	167°F		Telecommunica- tions System	Alcoa
Aluminum 356 Casting						Telecommunica- tions System	Alcoa
Beryllium Copper		Yes & No	104°F	257°F		Telecommunica- tions System	Beryllium Corp.
Copper		Yes & No	104°F	167°F		Telecommunica- tions System	Anaconda Chase
Gold		Yes & No	75°F	252°F		Telecommunica- tions System	Sel Rex Technic

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
Gold		Yes & No	104°F	167°F		Telecommunica- tions System	Sel Rex Technic
Indium		Yes & No	75°F to 149°F	257°F		Telecommunica- tions System	Indium Corp.
Nickel		Yes & No	75°F to 149°F	257°F		Telecommunica- tions System	International Nickel Corp.
Phosphorous Bronze		No	75°F	252°F		Telecommunica- tions System	American Brass
Silver		No	75°F	252°F		Telecommunica- tions System	American Platinum
Silver		Yes & No	104°F	167°F		Telecommunica- tions System	American Platinum
Solder	Type 60/40	Yes & No	75°F to 149°F	257°F		Telecommunica- tions System	Kester Federated
Rhod		Yes & No	104°F	167°F		Telecommunica- tions System	Sel Rex Technic Inc.
Nickel & Tin						Telecommunica- tions System	Sel Rex Technic Inc.

APPENDIX A (Cont'd)

MATERIAL	COMPOSITION	HERM. SEALED (YES-NO)	NORM. OPER. TEMP.	MAX. OPER. TEMP.	MAX. FAIL TEMP.	LOCATION (COORD)	MANUFACTURER & TRADE NAME
2014-T6 (QQ-A-327)	Silicon .5 to 1.2 Iron 1.0 Copper 3.9 to 5.0 Manganese .4 to 1.2 Magnesium .2 to .8 Chromium .1 Zinc .25 Titanium .15 Other .15 (Max. .05 for each) Aluminum Remainder	No					At request
6061-T6	Silicon .4 to .8 Iron .7 Manganese .15 to .4 Magnesium .15 Chromium .8 to 1.2 Zinc .25 Titanium .15 Other .15 (Max. .05 for each) Aluminum Remainder	No					At request
Butyl		No					At request

APPENDIX B

PHYSICAL PROPERTIES OF NON-METALLIC MATERIALS FOR MANNED SPACE VEHICLES

This material is excerpted from McDonnell Aircraft Corporation report 6792, revised April 1963, "Physical Properties of Non-Metallic Materials for Manned Space Vehicles."

Report 6792 has been prepared to establish maximum use temperatures for non-metallic materials to be used in the inhabited area of spacecraft. The indicated temperature limits are based upon laboratory tests using 100% oxygen atmosphere at 5 PSI absolute for 3-24 hours continuous usage without producing irritating or obnoxious odors. Toxicity vs. temperature limits are not based on actual tests but were compiled as a result of odor tests and a basic knowledge of chemical and thermal properties. In most cases the maximum temperatures shown were established by tests because of a current operating temperature. Some, in fact most of the materials listed will probably pass a higher temperature.

The charts are for use as guides to Design Engineers concerned with the selection of non-metallic or non-ceramic materials. In most cases materials are listed by popular chemical names. It is recognized that some Design Personnel may not be familiar with the popular chemical names; it is therefore recommended that "MIL Spec" materials, "MMS" (MAC Material Specifications) materials, "AMS" (Aeronautical Material Specification) material or trade name materials be identified chemically before consulting the charts.

The charts do not establish temperature limits for mechanical or electrical properties. Most of the materials can withstand much higher temperatures than those indicated. In selection of materials, it is desirable always to choose the highest temperature material available since higher temperature materials have more possibility of passing the odor and toxicity tests. Selection of lubricants and fluids must be based on whether the parts or systems are open within the cabin.

Enclosure 1 is included, Contaminants Recovered from Capsule Atmosphere of Mercury Flights (NASA Report), which presents the contaminants and the results in parts per million and actual weight in milligrams. Quantitative measurements were made by desorbing activated carbon which collected gases from the capsule atmosphere of Mercury flights 6, 7 and 8. In general the table shows that a safe atmosphere was maintained in the spacecraft and that odor tests conducted for use in the Mercury Spacecraft were an effective means of predicting the safety level of the atmosphere under operating conditions.

OLFACTORY AND NON-TOXIC PROPERTIES OF NON-METALLIC MATERIALS IN 100% OXYGEN AT 5 PSIA FOR 3-24 HOURS

NOTES: Metallic Materials are not shown, but are considered safe for use under the conditions and temperatures indicated on this chart.
* Material not tested at 160°F

Material	Source or Manufacturer	Specification	Maximum temperature for unobjectionable odor	Maximum temperature for non-toxic properties	Remarks
RUBBER MATERIAL (ALL FORMS)					
Neoprene		MIL-R-6855, Class II	250°F	250°F	
Neoprene (Sponge)		AMS-3197	250°F	250°F	Bendix Pigmy Connector with Neoprene insert.
Neoprene			250°F	250°F	
Buna N	Parker	SAE 120R, Class I	160°F	160°F	
Buna N	Plastic & Rubber Products Co.	MIL-P-5315	160°F	160°F	No. 1011-10
Buna N	Stillman Rubber Co.	MIL-P-5315	250°F	250°F	No. 457
Buna N		MIL-P-25732	80°F*	80°F*	Stillman compound SR 832-75 (Produced Strong Odor at 250°F)
Silicone		AMS-3195	250°F	250°F	
Silicone		AMS-3345	250°F	250°F	
Silicone	Dow Corning Corp.		360°F	360°F	Silastic S-2007.
Silicone	Dow Corning Corp.		160°F	160°F	No. 9711
Polyurethane	Dayton Rubber Co.		160°F	160°F	Stafoam U543
Polyurethane	Minneapolis-Honeywell Co.		160°F	160°F	Aeroflex M.S. 7083
Viton A	E.I. Dupont Co.		160°F	160°F	
Viton A			200°F	200°F	Splice inserts.
Natural Rubber	Stillman Rubber Co.	Commercial	160°F	160°F	Stillman compound No. SR 221-40.
Natural Rubber	Stillman Rubber Co.	Commercial	160°F	160°F	Stillman compound No. SR 222-60.
Natural Rubber	Seamless Rubber Co.	Commercial	80°F	80°F	Seamless Rubber compound No. RD-174.
Natural Rubber	Devol Co.	Commercial	90°F	80°F	Devol Co. Type S-9518 squeeze bulb, unsatisfactory at 125°F
Fairprene Rubber	E.I. Dupont Co.	Commercial	160°F	160°F	AIResearch Part No. 10-150949-8 Gasket
Rubber Base Foam	B.F. Goodrich Chemical Co.	Commercial	160°F	160°F	
Rubber Covered Cord(Flexible)	Heiland	Commercial	160°F	160°F	M.A.C. Part No. 45-81099, Heiland No. 302511.
Elastic Hose	Arbelet	Commercial	160°F	160°F	Arbelet elastic hose.
Latex open cell sponge with Peperon fabric on one side	Kennel Shoe Supply Co.	Commercial	150°F	150°F	Cemented sponge face to sponge face with EC 847 cement or with X4031 cement (King Chemical Co.).

OILFACTORY AND NON-TOXIC PROPERTIES OF NON-METALLIC MATERIALS IN 100% OXYGEN AT 5 PSIA FOR 3-24 HOURS - (Continued)					
Material	Source or Manufacturer	Specification	Maximum temperature for unobjectionable odor	Maximum temperature for non-toxic properties	Remarks
<u>THERMOPLASTICS</u>					
Acrylic	Rohm & Haas Co.	ML-P-8184	250°F	250°F	Flexiglass 55, as cast
Acrylic	Rohm & Haas Co.	ML-P-5425	250°F	250°F	Flexiglass II, as cast
Acrylic Resin	Columbia Tech. Corp.	Commercial	160°F	160°F	Flexiglass No. 2072
			212°F	212°F	Humiseal 1B15
Cellulose Acetate Butyrate	Eastman Chemical Co.	Commercial	250°F	250°F	Tenite Butyrate softened at 250°F.
Polyethylene	-	ML-P-3803, Type I	160°F	160°F	Zipper tubing produced strong offensive odor at 200°F.
Polyethylene	-	"	80°F*	80°F*	
Irradiated Polyethylene	Raychem Corp.	Commercial	250°F	250°F	Type RWT.
Irradiated Polyethylene	General Electric Co.	Commercial	80°F*	80°F	Zipper tubing made by Zipper Tubing Co. produced strong odor at 250°F. Specimen melted and adhered to bottom of desiccator.
Irradiated Polyethylene	Visking Co.	Commercial	250°F	250°F	Zipper Tubing No. ZT (Diam.) PT-10-C-OL.
Nylon	E.I. DuPont Co.	Commercial	250°F	250°F	Material softened, became tacky.
Wire with B-22 Nylon Covering	-	Commercial	160°F	160°F	Nylon 101
Polycarbonate	General Electric Co.	Commercial	160°F	160°F	Lexan
Vinyl & Copolymers	U.S. Rubber Co.	Commercial	200°F	200°F	Type AL Esacelite coated with U.S. vinyl dip.
Vinyl & Copolymers	Simonize Co.	Commercial	160°F	160°F	Vinyl Formal Sponge - Slight vanilla odor.
Vinyl & Copolymers	Simonize Co.	Commercial	160°F	160°F	Vinyl Formal Sponge cellulose filled.
Vinyl & Copolymers	-	"	80°F*	80°F*	Vinyl zipper tracks produced strong offensive odor at 200°F
Vinyl & Copolymers	U.S. Stoneware Co.	Commercial	80°F	80°F	Tygon No. B-44-3 vinyl tubing - produced strong odor at 160°F. Became tacky at 250°F.
Vinyl & Copolymers	U.S. Stoneware Co.	Commercial	80°F	80°F	Tygon Type S-22-1, produced strong odor at 125°F.
Vinyl & Copolymers	DeVilbiss Co.	Commercial	80°F	80°F	Type SR 24-R256, slightly pungent odor at 125°F.
Vinyl & Copolymers	DeVilbiss Co.	Commercial	80°F	80°F	Type DW-1 Vinyl plastisol squeeze bulb.
Vinyl Electrical Terminals and Knife Splices.	-		250°F	250°F	
Plastic Insulating Tubing	Minneapolis-Honeywell Co.	Commercial	160°F	160°F	Fiberglass Reinforced Vinyl (Part No. M.S. 6010).
Kel-F	3M Co.	Commercial	160°F	160°F	

OLFACTORY AND NON-TOXIC PROPERTIES OF NON-METALLIC MATERIALS IN LOW OXYGEN AT 5 PSIA FOR 3-24 HOURS - (Continued)

Material	Source or Manufacturer	See 151 stn	Maximum temperature for non-toxic properties	Maximum temperature for non-toxic properties	Remarks
<u>TERMOPLASTICS - (Continued)</u>					
Teflon	E. I. du Pont Co.	Commercial	Δ 482°F Δ 200°F	Δ 482°F Δ 200°F	SEE NOTE 1 Teflon-Fiberglass laminate, cover case slider dielectric and lamina 1500 mils. SEE NOTE 1
Union Sponge	Simons Co.	Commercial	180°F	180°F	Compound for engraved lettering.
Rohlex Black Filling Compound	Rohm & Haas Co.	Commercial	230°F	230°F	
<u>TERMOSET PLASTICS</u>					
Epoxy & Fiberglass	Coast Manufacturing Co. Shell Chemical Co.	Commercial	230°F 800°F	230°F 800°F	Cast F-120, 11 Epoxy Fiberglass laminate (6-10) cured for 30 min. at 200°F. Produced strong odor. (Asbestos such line.) Epoxy Fiberglass laminate (M.S. 6473).
Epoxy & Fiberglass	Minneapolis-Honeywell Co.	Commercial	160°F	160°F	
Polyester & Fiberglass	Coast Manuf. Co.	Commercial	230°F	230°F	Cast F-141.
Phenolic & Fiberglass	Coast Manuf. Co.	Commercial	230°F	230°F	Cast F-120.
Phenolic Bronze-Fiberglass Impregnated	Alkesech Wfg.	Commercial	160°F	160°F	
Rockbestos Wire-Glass and Asbestos Fiberglass Impregnated	-	Commercial	300°F	300°F	Fuse Black Holder - (F-2) Silicene-Fiberglass Laminate - Formica Co. (Weldable Epoxy Adhesive; All the Rubber; Eastman 910 adhesive).
Fuse Black Holder (SCD 45-7/727)	Formica Corp.	Commercial	210°F	210°F	Moderate odor product, not objectionable.
Melamine & Fiberglass	-	MIL-P-1500, Type GM	200°F	200°F	Material darkened from light to dark brown.
Phenolic & Cotton	-	MIL-P-1000, Type FG	250°F	250°F	Increases in thickness by 1/2, slight phenol odor - not objectionable.
Phenolic & Paper	-	MIL-P-13, Type PB	200°F	200°F	

1. Regardless of the maximum temperature anticipated for use, the reasons and specific usage of Teflon or Teflon containing products shall be submitted to McDonnell for further submittal to NASA for approval before calling out the material on a design drawing and using the material in an assembly.

OLEFACTORY AND NON-TOXIC PROPERTIES OF NON-METALLIC MATERIALS IN 100% OXYGEN AT 5 PSIA FOR 3-24 HOURS - (Continued)

Material	Source or Manufacturer	Specification	Maximum temperature for unobjectionable odor	Maximum temperature for non-toxic properties	Remarks
THERMOSET PLASTIC - (Continued)					
Urethane Foam (Rigid)	Nopco Chem. Co.	Commercial	160°F	160°F	Lockfoam C-605.
Urethane Foam (Rigid)	Emerson & Cuming Inc.	Commercial	80°F*	80°F*	Ecco Foam FF with 12-6 Catalyst (unsatisfactory at 250°F)
Urethane Foam (Rigid)	Pittsburg Plate Glass Co.	Commercial	160°F	160°F	Selectro Foam 6002-6003.
Urethane Foam (Rigid)	Witco Chem. Co.	Commercial	250°F	250°F	Witco Faure: P400, P420 foam.
Urethane Foam (Rigid)	Nopco Chem. Co.	Commercial	160°F	160°F	EX100 Nopco Lockfoam.
Urethane Foam (Rigid)	Nopco Chem. Co.	Commercial	160°F	160°F	Lockfoam G502 (cured 2 hours @ 180°F)
Urethane Foam (Rigid)	Nopco Chem. Co.	Commercial	180°F	180°F	Lockfoam E302 with water added (Density 1.5 lbs/cu. ft., cured 1 1/2 hour @ 180°F).
Urethane Foam (Rigid)	Nopco Chem. Co.	Commercial	250°F	250°F	Lockfoam A206.
Epoxy Foam (Rigid)	Bakelite Co.	Commercial	160°F	160°F	Bakelite Thermosetting Epoxy Resin Foam. (M.S. 6293C) Slight odor produced.
Epoxy - Polyimide	Shell - General Mills	Commercial	250°F	250°F	P.S. 14030, Compound III (Epon 828 and Versamid 125-70 parts - 30 parts) with Micro Balloons (Phenolic) 50 parts: Cure 1 hr @ 200°F.
Epoxy	-	Commercial	250°F	250°F	Biscuits K-1 with K-4 Accel. (Epoxide Battery Case Mat.)
Epoxy	Houghton Lab. Inc.	Commercial	250°F	250°F	Rysol 6040, C-1 Hardner, 156 Filler.
Epoxy	Furane Plastics Inc.	Commercial	250°F	250°F	Epocast 107.
Epoxy	Epoxylite Corp.	Commercial	300°F	300°F	Epoxylite No. 801.
Epoxy	Electronic Production and Development Co.	Commercial	80°F	80°F	P.S. 14032, Type 1, Joggle Compound, Cured 1 hr. @ 200°F.
Epoxy	-	-	80°F	80°F	Epoxy No. TC-459. Strong odor produced at 160°F.
Epoxy	-	-	160°F	160°F	P.S. 14043 Epoxy - DTA and Glass Flock. (Plastic corner of Astronaut Couch Corner).
Epoxy	Minneapolis-Honeywell Co.	Commercial	160°F	160°F	Thermosetting Epoxy Resin (M.S. 6020M).
Epoxy	Emerson & Cuming Inc.	Commercial	200°F	200°F	Stycast No. 2651 epoxy casting resin.
Polyester	-	-	160°F	160°F	Laminate per P.S. 14031, Compound VI
Mylar-Paper Laminated Map	St. Louis Mapping Co.	Commercial	180°F	180°F	Map with Map Colors.
Mylar and Quinterra	AIRsearch Mfg.	Commercial	300°F	300°F	
Mylar Coated White	-	Commercial	80°F	80°F	M.S. W-138-H-2 (produced offensive odor at 160°F)
Mylar Coated Card Stock	-	-	160°F	160°F	Mylar coated card stock-3 ply Stratmore.

OLFACTORY AND NON-TOXIC PROPERTIES OF NON-METALLIC MATERIALS IN 100% OXYGEN AT 5 PSIA FOR 3-24 HOURS - (Continued)

Material	Source or Manufacturer	Specification	Maximum temperature for no-jettisoning odor	Maximum temperature for non-toxic properties	Remarks
<u>THERMOSET PLASTIC - (Continued)</u>					
Nylar Film - Matte one side	Keuffel-Esser	Commercial	160°F	160°F	K&E No. 103
Diallyl - Phthalate	Minneapolis-Honeywell Co.	Commercial	160°F	160°F	Connector insert, Honeywell Part No. 45386.
Ecco Bond 56C	Emerson & Cuming Inc.	Commercial	200°F	200°F	Ecco Bond 56C (Thinner 10% by wt. with Toluene)
Engraving Stock	Formica Corp.	MI-P-704, Type ADP	160°F	160°F	Formica Grade 35-1.
<u>FABRICS, FELT, & WEBBING</u>					
Dacron Webbing	Phoenix Trimming	MI-M-45361	160°F	160°F	Dacron harness webbing.
Nylon Cord	-	-	250°F	250°F	Untreated nylon tying tape (sort).
Cotton Duck	-	CCC-C-41, Type I Hard	180°F	180°F	No. 12 cotton duck.
Cotton Webbing	-	MI-M-530, Type II Class 4	180°F	180°F	
Nylon Webbing	-	MIL-W-4080C, Bond. B	160°F	160°F	Resin Treated
Map Sized Cotton Cloth	St. Louis Mapping Co.	Commercial	80°F*	80°F*	Produced hot ironing color at 250°F.
Yellow & Gray Duct Mat.	Arrowhead Products	Commercial	250°F	250°F	M.A.C. Part No. 4-C301-3 (Max. cure).
Wool Felt	AirResearch Mfg.	Commercial	160°F	160°F	Wool felt with fungus preventive.
Vinyl Coated Nylon Fabric	Cooley, Inc.	MIL-C-2076, Type I, Class II	160°F	160°F	
Neoprene Coated Nylon Fabric	Ponca Canvas Products Co.	Commercial	160°F	160°F	16 ounce weight, silver color.
Neoprene Coated Nylon Fabric	E.I. DuPont Co.	Commercial	160°F	160°F	Fairprene No. 5753.
Glass (untreated)	-	-	400°F	400°F	
<u>PAPER, CORK, & LEATHER</u>					
Leather	-	-	160°F	160°F	Oak grained, unskived leather.
Paper, Kraft	Kraft Paper Co.	Commercial	160°F	160°F	Transformer insulation (M.S. 6542 - Minneapolis-Honeywell).

OLFACTORY AND NON-TOXIC PROPERTIES OF NON-METALLIC MATERIALS IN 100% OXYGEN AT 5 PSIA FOR 3-24 - (Continued)

Material	Source or Manufacturer	Specification	Maximum temperature for unobjectionable odor	Maximum temperature for non-toxic properties	Remarks
<u>PAINTS, FINISHES & COATINGS</u> Silicone (Modified) Silicone (Modified)	Andrew Brown Co. Sherwin-Williams Paint Co.	Commercial Commercial	250°F 250°F	250°F 250°F	XA-193 & XA-194 Space Capsule Coating. Ajax Modified Silicone Insulating Varnish V61V25.
Silicone Silicone	Dow Corning Corp.	Commercial Commercial	300°F 250°F	300°F 250°F	DC 997 Silicone Varnish. X3-4004 Silicone primer overcoated with space capsule coating.
Epoxy	Dennis Chemical Co.	Commercial	250°F	250°F	Epon mix insulating lacquer No. F-174-61A & No. F-174-61B. Baked @ 150°F for 1 hour.
Epoxy	Sherwin-Williams Paint Co.	Commercial	300°F	300°F	Cati-coat, F55BP7 (207970-207990)
Epoxy	D.J. Peters Co.	Commercial	80°F*	80°F*	Poly-EP Logic Board Spray (Cured 1-1/2 hours @ 160°F).
Epoxy	Houghton Lab. Inc.	Commercial	200°F 180°F	200°F 150°F	Hysol 623E modified epoxy coating. Poly-EP Logic Board Spray (2 parts Epoxy, 1 part Polyamide, 3 spray coats - 5 min. bake @ 200°F between coats, 1 or 2 hour bake at 200°F after final coat)
Urethane Coating	Coast Pro-Seal Mfg. Co.	Commercial	80°F*	80°F*	Polyurethane coating No. 798 - Produced strong offensive odor - became soft and tacky at 250°F.
Silver Print Conductive Coating	General Cement Mfg. Co.	Commercial	250°F	250°F	
Phenol Formaldehyde Varnish		Commercial	80°F*	80°F*	TT-P-119 Varnish (Produced strong odor at 200°F after 150°F cure for 1 hour.)
Lacquer and Surfacers		MIL-L-7178 MIL-S-974	200°F 200°F	200°F 200°F	On panel
Spec. M.S. 6668 White Paint	Glidden Co.	Commercial	80°F	80°F	M.S. 6668, Paint Spec. No. 043-122-301.
Silk Screen Paint No. D22R2	Sherwin Williams Co.	Commercial	160°F	160°F	No. D22R2, Blacs
Flat Black Lacquer	Minneapolis-Honeywell Co.	Commercial	160°F	160°F	Part No. 418101, Lacquer on nameplate.
Flat Black Lacquer	Minneapolis-Honeywell Co.	Commercial	160°F	160°F	Part No. 446977, Lacquer on synconverter switch.
EC-1103 Coating	3M Co.	Commercial	200°F	200°F	
303 Stainless Steel with Tin Plate and Lacquer Finish with Compressed Glass Kovar	AIResearch Mfg.	Commercial	160°F	160°F	

OLFACTORY AND NON-TOXIC PROPERTIES OF NON-METALLIC MATERIALS IN 100% OXYGEN AT 5 PSIA FOR 3-24 - (Continued)

Material	Source or Manufacturer	Specification	Maximum temperature for unobjectionable odor	Maximum temperature for non-toxic properties	Remarks
<u>LUBRICANTS & FLUIDS</u>					
Silicone Grease	General Electric Co.	Commercial	250°F	250°F	G-300 Silicone Grease
Silicone Grease	Shell Oil Co.	Commercial	250°F	250°F	Shell EXR Grease B
Silicone Grease	Shell Oil Co.	Commercial	250°F	250°F	Shell EXR Grease H
Silicone Grease	Dow Corning Corp.	Commercial	250°F	250°F	DC-4 Grease
Silicone Oil	General Electric Co.	Commercial	250°F	250°F	Versilube F-50 Silicone Lubricating Oil.
Silicone Fluid	Dow Corning Corp.	Commercial	160°F	160°F	No 200 Fluid
Fluoro Grease	Hooker Electrochemical Co.	Commercial	250°F	250°F	Fluorolube Grease Type "LC"
Fluoro Oil	Hooker Electrochemical Co.	Commercial	250°F	250°F	Fluorolube "FS" Light Grade Oil
Andok "C"	Esso Standard Oil Co.	Commercial	80°F**	80°F~	Objectionable Odor at 210°F
Oxylube Thread Sealant	Drillube Corp.	Commercial	250°F	250°F	Oxylube Thread Sealant No. 702
Dry Film Lubricant	Electrofilm Corp.	Commercial	250°F	250°F	Electrofilm 66C
Dry Film Lubricant	Alpha Corp.	Commercial	250°F	250°F	Molykote
Dry Film Lubricant	Everlube Corp.	Commercial	250°F	250°F	Everlube
Dry Film Lubricant	Drillube Corp.	Commercial	250°F	250°F	Drillube
Dry Film Lubricant	Hohman Plating Co.	Commercial	250°F	250°F	Surf-Kote
Synthetic Base (Diester)		Commercial	80°F	80°F	
Coolanol #35	Monsanto Chemical Co.	Commercial	80°F	80°F	Offensive odor at 120°F
Dow Corning #7 Compound	Dow Corning Corp.	Commercial	200°F	200°F	
Led-Plate #250 Anti-Seize Compound		Commercial	200°F	200°F	
Self Locking Hex Nut		Commercial	300°F	300°F	Part No. 58723M-02 Lubricated with Everlube 810
OS-139 Heat Transfer Fluid	Monsanto Chemical Co.	Commercial	80°F	80°F	Very pungent odor at 160°F
Jo-Bolt Components & Lubrication Treatments		Commercial	250°F 400°F 400°F 400°F	250°F 400°F 400°F 400°F	Aluminum nuts, carbo wax treated A-286 Components, carbo wax treated A-286 Components, carbo wax and Dag treated A-286 Components, Dag 223 and No-oxide treatment

OLFACTORY AND NON-TOXIC PROPERTIES OF NON-METALLIC MATERIALS IN 100% OXYGEN AT 5 PSIA FOR 3-24 - (Continued)

Material	Source or Manufacturer	Specification	Maximum temperature for non-toxic properties	Maximum temperature for non-toxic properties	Remarks
LUBRICANTS & FLUIDS - (Continued)					
3-Epoxy Components & Lubrication Treatments					
Everlube 620	Everlube Corp.	Commercial	400°F	400°F	A-236 Components, Deg 223 treated
MAC-169	Monsanto Chemical Co.		400°F	400°F	A-236 Components, Everlube and 3% oxide treated
ADHESIVES			80°F	80°F	A-236 Components, Everlube treated
			80°F	80°F	Lubricated with Mat. Lube #1 - Unsatisfactory at 300°F
			300°F	300°F	Lubricated with Translube - Unsatisfactory at 300°F
			300°F	300°F	
Epoxy - Amine	Armstrong Products Co.	Commercial	160°F	160°F	Armstrongs C-2 with Activator "A" cured
Epoxy - Amine	Armstrong Products Co.	Commercial	160°F	160°F	Armstrongs A-2 with Activator "E" cure: 1 hour at 200°F
Epoxy - Amine	3M Co.	Commercial	250°F	250°F	EC-140y Epoxy - EC-147y Amine Cure, heat cured
Epoxy - Amine	Shell Chemical Co.	Commercial	160°F	160°F	Epon 8 - Curing Agent "A" (100 parts to 6 parts mix), cure: 1-1/2 hours at 200°F
Epoxy Polyamide	Shell Chemical Co.	Commercial	250°F	250°F	Epon 8 - Versamid 125 (1/4-3/4, cure: 1 hour at 200°F)
Vinyl - Phenolic	Bloomington Rubber Co.	Commercial	250°F	250°F	FM 47 Type "O" Adhesive
Epoxy	Emerson & Cuming Inc.	Commercial	160°F	160°F	Eccobond #70 C Epoxy Adhesive Cure: 1 hour at 200°F
Epoxy	Shell Oil Co.	Commercial	160°F	160°F	Shell Epon Adhesive No. 6
Epoxy	Carl H. Biggs Co.	Commercial	80°F	80°F	Biggs R-313 Epoxy Resin Adhesive
Epoxy	Emerson & Cuming Inc.	Commercial	160°F	160°F	Eccobond #26 Epoxy Adhesive (Used in Carlton Control Valve)
Adhesives - 16840	W. S. Chamberlain & Co.	Commercial	80°F	80°F	Without heat cure and with 1-1/2 hour cure at 200°F. Produced strong bond at 300°F
Bonding Agent R314	Carl H. Biggs Co.	Commercial	160°F	160°F	Hardner "A"
Caram 214	AI Research Mfg.	Commercial	160°F	160°F	Bonding Material
Adhesive, Pressure Sensitive	Dow Corning Corp.	Commercial	300°F	300°F	Pressure Sensitive Adhesive NE71
Adhesive, Pressure Sensitive	3M Co.	Commercial	300°F	300°F	Pressure Sensitive Adhesive Y-9010

OLFACTORY AND NON-TOXIC PROPERTIES OF NON-METALLIC MATERIALS IN 100% OXYGEN AT 5 PSIA FOR 3-24 - (Continued)

Material	Source or Manufacturer	Specification	Maximum temperature for unobjectionable odor	Maximum temperature for non-toxic properties	Remarks
<u>CEMENTS</u>					
Neoprene-Phenolic	3M Co.	Commercial	250°F	250°F	EC-847
Buna N-Phenolic	3M Co.	Commercial	80°F	80°F	EC-776
Neoprene	3M Co.	Commercial	250°F	250°F	EC-870
Silicone	Dow Corning Corp.	Commercial	250°F	250°F	A-4000 Cement with XY-27 Catalyst
Stabond Cement	American Laitex Co.	Commercial	80°F*	80°F*	Stabond C-136 Cement - strong odor produced at 250°F
Kodak Dry Mount Cement	Eastman Chemical Co.	Commercial	160°F	160°F	For laminating Map to Card stock.
<u>SEALANTS (ELASTOMERS)</u>					
Silicone Primer (Encapsulating)	3M Co.	Commercial	250°F	250°F	EC-1694 Primer for use with EC-1663 Potting Compound
Silicone (Encapsulating)	3M Co.	Commercial	250°F	250°F	EC-1663 Potting Compound
Silicone (Structural RTV)	General Electric Co.	Commercial	400°F	400°F	RTV-682 Silicone Potting Compound (Produced strong musty odor at 250°F)
Silicone (RTV)	Products Research Co.	Commercial	400°F	400°F	RTV-90 Sealant
Silicone (RTV)	Dow Corning Corp.	Commercial	250°F	250°F	PR 1910-8 Silicone RTV Sealant
Silicone (RTV)	Dow Corning Corp.	Commercial	250°F	250°F	RTV-Q-3-0121 Silicone Sealant
Silicone (RTV)	Dow Corning Corp.	Commercial	300°F	300°F	RTV-731 Silicone Sealant
Urethane	Coast Manufacturing Co.	Commercial	80°F	80°F	RTV-501 Silicone Rubber
Oil Resistant Elastomer	Perkin-Elmer Corp.	Commercial	160°F	160°F	Coast Proseal #777 Potting Compound
Loctite "A"	Perkin-Elmer Corp.	MIL-S-22473 Grade A	250°F	250°F	Anti-Tamper Compound EC-1252
Loctite "C"	Perkin-Elmer Corp.	MIL-S-22473 Grade C	250°F	250°F	
<u>TAPES</u>					
Silicone & Fiberglass	Permacel Corporation	Commercial	250°F	250°F	P-211 Permacel Tape
Fiberglass with Adhesive	3M Co.	MIL-I-15126	80°F*	80°F*	No. 27 Objectionable odor produced at 300°F
Fiberglass with Adhesive	Minneapolis-Honeywell Co.		160°F	160°F	M.S. 6771

OLEFACTORY AND NON-TOXIC PROPERTIES OF NON-METALLIC MATERIALS IN 100% OXYGEN AT 5 PSIA FOR 3-24 - (Continued)

Material	Source or Manufacturer	Specification	Maximum temperature for unobjectionable odor	Maximum temperature for non-toxic properties	Remarks
<u>TAPES - (Continued)</u>					
Polyester	3M Co.	Commercial	250°F	250°F	Scotch Polyester Tape #5
Polyester	Minneapolis-Honeywell Co.	Commercial	160°F	160°F	M.S. 6856, Pressure sensitive - thermosetting
Thermal Sensing Element Patch		Commercial	250°F	250°F	Conolon 506-81 over Narmco Tape 103, Type I film and Narmco Tape 103 Type III and IV (50%-50%)
Heat Reflective	3M Co.	Commercial	250°F	250°F	Y-9050
Electrical Tape	3M Co.	Commercial	250°F	250°F	Scotch #69 Electrical Tape
Magnetic Tape	3M Co.	Commercial	160°F	160°F	Type 490
Magnetic Tape	3M Co.	Commercial	160°F	160°F	Type 499
<u>GASKETS & PACKINGS</u>					
Asbestos-Rubber	See Rubber Materials Section Above				
Asbestos-Rubber Graphite	See Rubber Materials Section Above				
Cork-Rubber	See Cork Materials Section Above				
Rubber	See Rubber Materials Section Above				
Asbestos and Binder	Consult Materials and Process Development Department				
Plastic	See Plastic Materials Section Above				
<u>INKS & NAMEPLATES</u>					
Ink	Banner Rubber Stamp Co.	Commercial	250°F	250°F	#448 Black and White Marking Ink
Ink	Organic Products Co.	Commercial	200°F	200°F	VE200 Red Marking Ink
Ink	Organic Products Co.	Commercial	160°F	160°F	100 Series Green Ink
Nameplate (Metal)	Nelson Nameplate Co.	Commercial	250°F	250°F	Anodized Aluminum foil type nameplate. Any dyed, anodize and etched printing type nameplate is satisfactory if all photo emulsion is removed.
Nameplate (Metal)	AlResearch Mfg.	Commercial	160°F	160°F	Metalcalcs with adhesive backing
Nameplate (Metal)	AlResearch Mfg.	Commercial	250°F	250°F	Metal foil nameplates with heat or solvent activated adhesive.
Nameplate (Metal)	AlResearch Mfg.	Commercial	160°F	160°F	Metal foil identification plates with EC-583 adhesive (3M Co.) Heat or Solvent applied.
Nameplate (plastic)	AlResearch Mfg.	Commercial	160°F	160°F	V-71 Cals.
Nameplate (plastic)	PEE-CEE Tape & Label Co.	Commercial	200°F	200°F	PEE CEE 1001 Mylar Pressure Sensitive Label.

OLFACTORY AND NON-TOXIC PROPERTIES OF NON-METALLIC MATERIALS IN 100% OXYGEN AT 5 PSIA FOR 3-24 - (Continued)					
Material	Source or Manufacturer	Specification	Maximum temperature for no objectionable odor	Maximum temperature for non-toxic properties	Remarks
MISCELLANEOUS COMPONENTS					
Thermoflex RF-300	Johns Manville Co.	Commercial	200°F	200°F	
No XR-5005 Scotchcast Resin, 55-9-100 Chrysler Cycle Weld, M-19 Lamination	AIResearch Mfg.	Commercial	300°F	300°F	
"HO" Varglass-Fiberglass Braid with light treatment of Resin	AIResearch Mfg.	Commercial	160°F	160°F	
Fl41 Prepreg - AF106 Adhesive Aluminum Core Honeycomb		Commercial	160°F	160°F	
Aluminum Face-Aluminum Core Honeycomb Structure Bonded with FM47 Adhesive		Commercial	250°F	250°F	
El Glass Insulator	AIResearch Mfg.	Commercial	160°F	150°F	
Warning Life Assembly	Grimes Mfg. Co.	Commercial	200°F	200°F	M.A.C. Part No. 45-7720-31 & 45-7720-117
Mallory Mercury Battery	Mallory	Commercial	200°F	200°F	
Rotary Potentiometer		Commercial	160°F	150°F	M.A.C. Part No. 45-68717-5
Astronaut Pencil	C.H. Swan Co.	Commercial	160°F	160°F	Astronaut Pencil, Tablo 0006 - All
Capacitor, Paper Type	Grimes Mfg. Co.	Commercial	250°F	250°F	Cornell Dubilier No. P40P33
Microswitch	AIResearch Corp. Hayden Mica Co., Inc.	Commercial	160°F	160°F	Part No. 54-501-003 Part No. 61526
Grade 45, Silica Gel	Davidson Chemical Cor.	Commercial	250°F	250°F	
Microdot 50-3804 Cable	Microdot Inc.	Commercial	200°F	200°F	
Soap Base Crayoff Crayons	Crayoff Corporation	Commercial	250°F	250°F	Applied, then washed off with cold tap water and wiped dry.

OLFACTORY AND NON-TOXIC PROPERTIES OF NON-METALLIC MATERIALS IN 100% OXYGEN AT 5 PSIA FOR 3-24 - (Continued)

Material	Source or Manufacturer	Specification	Maximum temperature for unobjectionable odor	Maximum temperature for non-toxic properties	Remarks
<u>MISCELLANEOUS COMPONENTS - (Continued)</u>					
Nafil Resin Foam		Commercial	160°F	160°F	Cured at 160°F for 2 hours at 5 PSI
Nafil Resin Foam with Dennis Epoxy	Dennis Chemical Co.	Commercial	160°F	160°F	Cured at 160°F for 2 hours at 5 PSI
Electrical Hook-up Wire	Beldon Mfg. Co.	MIL-W-16878 Type B	200°F	200°F	No. 8503
Printed Circuit Board	Taylor Fibre Corp.	Commercial	200°F	200°F	No. GEC-500
AN Nuts with Vulcanized Fiber Inserts (Elastic Stop Nuts)		Commercial	250°F	250°F	
Microphone Assy		Commercial	160°F	160°F	M.A.C. Part No. 45-85035-1
Wire, RG 58/U	Plastoid Corp.	Commercial	80°F*	80°F*	Slightly objectionable and mildly pungent odor at 200°F
Wire, 20GA	Brand Rex Cable Corp.	Commercial	80°F*	80°F*	Slightly objectionable and mildly pungent odor at 200°F
Connector	Cannon	Commercial	80°F*	80°F*	Slightly objectionable and mildly pungent odor at 200°F
Connector	Viking	Commercial	80°F*	80°F*	Slightly objectionable and mildly pungent odor at 200°F
Terminal Block	Jones	Commercial	80°F*	80°F*	Slightly objectionable and mildly pungent odor at 200°F
Circuit Breaker	Heinemann Electric Co.	Commercial	250°F	250°F	No. 6250

CONTAMINANTS RECOVERED FROM CAPSULE ATMOSPHERE OF MERCURY FLIGHTS

ENCLOSURE 1

NOTES: General - Concentrations given are approximate and represent the parts per million and the actual weight in milligrams that would be in the 60 cubic foot cabin area at 25°C.

1 Data from N. Irving Sax, Dangerous Properties of Industrial Materials
2 Preliminary Information.

CONTAMINANT	<u>1</u> MAC PPM IN AIR	MA-6 PPM SCRUBBED	MA-6 MG SCRUBBED	MA-6 PPM FLIGHT	MA-6 MG FLIGHT	MA-7 PPM FLIGHT	MA-7 MG FLIGHT	MA-8 PPM FLIGHT	MA-8 MG FLIGHT
Vinylidene Chloride	500	1.44	3.3	8.9	20.2	1.18	2.7	3.81	8.7
Benzene	35	27.1	50.0	8.83	16.3	25.5	47.1	2.88	5.3
Vinyl Chloride	500	- -	- -	5.89	8.7	- -	- -	Trace	Trace
Methyl Chloroform	100	Trace	Trace	1.46	4.6	1.46	4.6	2.03	6.4
Methylene Chloride	500	Trace	Trace	1.15	2.3	0.896	1.8	- -	- -
P-Dioxane	100	- -	- -	0.865	1.8	- -	- -	Trace	Trace
Unidentified	- -	- -	- -	- -	2.1	- -	- -	Trace	Trace
Cyclohexane	100	- -	- -	0.603	1.2	0.151	0.3	0.302	0.6
Toluene	200	25.7	56.0	0.597	1.3	4.09	8.9	7.16	15.6
Methyl Alcohol	200	- -	- -	0.568	0.43	2.11	1.6	Trace	Trace
Ethyl Alcohol	1000	Trace	Trace	0.156	0.17	0.156	0.17	- -	- -
Trichlorofluoromethane	1000	Trace	Trace	0.151	0.49	0.585	1.9	Trace	Trace

CONTAMINANTS RECOVERED FROM CAPSULE ATMOSPHERE OF MERCURY FLIGHTS (Continued)

CONTAMINANT	MAC PPM IN AIR	MA-6 PPM SCRUBBED	MA-6 MG SCRUBBED	MA-6 PPM FLIGHT	MA-6 MG FLIGHT	MA-7 PPM FLIGHT	MA-7 MG FLIGHT	MA-8 PPM FLIGHT	MA-8 MG FLIGHT
Formaldehyde	5	Trace	Trace	--	--	--	--	--	--
Freon II	1000	4650	15100	151	490	2310	7500	262	850
Carbon Dioxide	5000	3560	3700	3120	3240	10880	11300	1320	1370

APPENDIX C

DYNASOAR SPACE CABIN MATERIALS LIST

The source of this data is The Boeing Corporation. The list is approximately 30% complete.

I. Plastics

A. Thermoplastic Materials

1. Acrylic

- a. MIL-P-5425
- b. MIL-P-8184
- c. MIL-P-8257

- 2. Cellulose acetate (MIL-O-8587)
- 3. Cellulose Butyrate (MIL-P-3414)
- 4. Kel-F (Polychlorotrifluoroethylene AMS 3650A)
- 5. Nylon (MIL-P-17091)
- 6. Polyethylene (MIL-P-3083)
- 7. Polypropylene
- 8. Polystyrene

- a. Rexolite - cross linked styrene (MIL-P-3827A)
- b. Styrene Rubber Copolymers (BMS-8-35)
- c. Thermoplastic Polystyrene

- 9. Polyvinyl Chloride (MIL-P-3410)
- 10. Polyvinylidene Chloride (MIL-P-3411)
- 11. Polyvinyl Butyral (MIL-G-8602)
- 12. Teflon 100X - Polytetrafluoropropylene
- 13. Teflon - Polytetrafluoroethylene (AMS 3651)

B. Thermosetting Materials

1. Polyester

- a. Common Polyesters Resin (MIL-R-7575A)
- b. Tri-Allyl-Cyanate (TAC) Resin (MIL-R-25042)

- 2. Epoxy Resin (MIL-R-9300)
- 3. Phenolic Resin (MIL-R-9299)
- 4. Silicone Resin (MIL-R-25506)
- 5. Phenyl Silane (MIL-R-9299)
- 6. Alkyd Resins (MIL-M-14E)
- 7. Melamine (MIL-P-15037)

These listed specifications are for Reference only.

II. Elastomers

- A. Acrylonitrile
- B. Natural
- C. Silicone (G. E. -RTV-60)
- D. Neoprene - Polymers of Chloroprene

- E. Butyl - Isobutene and isoprene or butadiene
- F. Polyurethane - diisocyanate and glycol - adipic acid esters
- G. Hypalon - chlorosulfonated polyethylene

III. Lubricants

- A. Solid Film Dry Lubricants - BMS -3-3
- B. Greases

- 1. Petroleum oil thickened with Sodium, Calcium or Lithium Soaps.

- a. MIL-G-3545 Lubricating Grease, High Temperature
- b. MIL-G-7711 Lubricating Grease, General Purpose
- c. MIL-G-7187 Grease, Graphite, Aircraft Lubricating

- 2. Synthetic oil thickened with various thickeners

- a. MIL-G-7118 Grease, Aircraft Gear & Actuator Screw, Diester type oil, Lithium Soap Thickener
- b. MIL-G-7421, Grease, Extreme Low Temperature Diester Type oil, Lithium Soap Thickener
- c. MIL-G-25013 Ball & Roller Grease, Extreme High Temperature, Silicone Fluid, thickened with indanthrene type thickener.
- d. MIL-G-25760 Ball & Roller Grease, Wide Temperature Range, Pentaerythritol ester fluid, aryl urea thickener or other ester type with indanthrene type thickener

- 3. Radiation Resistant Grease

- C. Fluids

- 1. Petroleum Oil - MIL-L-7870 - Lubricating Oil, Low Temperature
- 2. Synthetic Diester type MIL-L-6058 - Lubricating Oil Aircraft Instrument
- 3. Synthetic Silicone Type
 - a. General Electric Versilube F-50
 - b. Dow Corning F-60

IV. Sealants

- A. BAC - 5010

- 1. Type 2

- a. Monsanto RF 2905
- b. Catalin 726

- c. Casophen RS-216
 - d. Bostik 1007
- 2. Type 5
 - a. Bostik 1008
- 3. Type 12 (BMS-5-55)
 - a. Minnesota Mining & Mfg. EC-1128
- 4. Type 30 (BMS-5-43)
 - a. Dupont 5458
- 5. Type 34 (BMS-5-56)
 - a. Minnesota Mining & Mfg. EC 873
- 6. Type 38 (BMS-5-29)
 - a. Minnesota Mining & Mfg. EC-776R
 - b. Epon 828
 - c. Epon 812
 - d. Versamid 115
 - e. Versamid 125
 - f. Hysol 2022
 - g. SaCo 2862, Comp. I
 - h. Hysol AK-7
 - i. SaCo 2862, Comp. II
 - j. Cement Epoxy Polyamide
- 7. Type 40 (BMS-5-14)
 - a. Pro-Seal 590 M
 - b. U.S. Rubber M-6249
- 8. Type 42 (BMS-514)
 - a. Dow Corning Silastic Adhesive S-2200
 - b. Dow Corning A4094 Primer
- 9. Type 44 (BMS-519)
 - a. PR-9021-A-1
 - b. PR-9021-A-2
 - c. PR-9021-A-4
 - d. PR-9021-B-1
 - e. PR-9021-B-2
 - f. Pro-seal 719-A-2

- g. Pro-seal 719-B-2
 - h. 3202-B-1
 - i. CS-3293-B-2
- 10. Type 45 (BMS-5-58)
 - a. Dow Corning RTV-Silastic 501 (Catalyst A)
 - b. Dow Corning A-4094 Primer
- 11. Type 46
 - a. Dow Corning A-4000 - Silicone Adhesive
 - b. Dow Corning A-4014 - Primer
 - c. Dow Corning A-4000 - Catalyst
- 12. Type 47
 - a. Mystic A-117, Silicone
 - b. Corning C-269, Silicone Adhesive
- 13. Type 48 (BMS-5-30)
 - a. Bostik 4040
 - b. Minnesota Mining & Mfg. EC1458
- 14. Type 49 (BMS-5-34)
 - a. Churchhill 3C-90
- 15. Type 50 (EMS-5-36)
 - a. Eastman 910
- 16. Type 51
 - a. Pro-Seal 501
- 17. Type 53
 - a. Gaco-N-29 Adhesive
 - b. Gaco-N-39 Accelerator
 - c. Gaco-N-15 primer
- 18. Type 54 (BMS-5-25)
 - a. Epon 901 & Catalyst B-1
 - b. Epon 901 & Catalyst B-2
 - c. Epon 901 & Catalyst B-3

19. Type 55

a. Thixon IB

B. BMS-5-17, HT-424

C. BMS-5-20, Harmtape 102, Types 1 and 2

D. BMS-5-15, AF-30/EC-1593

V. Adhesives

A. BMS-5-33 (Pressure Sealing RTV Silicones)

1. Dow Corning 3-0014
2. General Electric RTV-90
3. Products Research PR-1910
4. Coast Pro-Seal 792
5. Minnesota Mining & Mfg. Co. 1667

VI. Interior Finishes

A. Alkyd

1. MIL-P-6889A primer
2. MIL-P-8585 primer
3. TT-E-489 enamel
4. TT-E-527

B. Vinyl Chloride Polymers

1. MIL-P-15930 primer
2. MIL-E-15935 enamel

C. Vinyl Acetal

1. MIL-G-8514 wash primer
2. MIL-T-15328 wash primer

D. Catalyzed Epoxy

1. BMS-10-11 Type 1 primer
2. BMS-10-11 Type 2 topcoat

E. Silicones

1. Dow Corning 805, resin
2. Dow Corning 806, resin
3. Dow Corning 807, resin

F. Chlorinated Materials

1. Chlorinated Rubber (Parlon)
2. Chlorowax 70
3. Arochlor 1254

G. Polyurethanes

1. Mobay Co. Mondur CB-75 with Multron Resins

H. Nitrocellulose and Lacquers

1. MIL-L-7178
2. MIL-L-6805

I. Acrylic

1. Sherwin Williams M49YC10 enamel

APPENDIX D

THERMAL DECOMPOSITION AND TOXICITY DATA

FOR SELECTED ORGANIC MATERIALS

The Boeing Company, in 1959, initiated a program to study the thermal degradation of certain selected materials which might be employed in space cabins. This study is reported in Boeing Company Document No. D2 90202, portions of which are discussed herein. The laboratory studies included thermogravimetric analysis of individual materials, chemical identification of breakdown products, and relative indication of acute animal toxicity. These tests were conducted at reduced pressure under conditions simulating hypothetical space cabin environments.

A Stanton automatic recording thermogravimetric balance was used to determine the characteristic temperature profiles of the materials under study. To simulate a reduced pressure environment, the thermogravimetric balance was operated in an altitude chamber at 18,000 ft. (7.35 psia). Chemical analyses were made by gas chromatography and mass spectrometry. A Kitagawa Toxic Gas Analyzer was used for low-level carbon monoxide determinations. Several groups of materials, primarily elastomers and plastics were selected for the initial evaluation program. The decomposition temperatures, ranges, and other data from the thermogravimetric analyses are shown in Table 23.

The initial weight loss is the lowest temperature at which weight loss was recorded. These losses are usually due to loss of residual solvent or absorbed water but in some instances may be caused by very slight degradation.

The empirical decomposition temperature is arbitrarily taken as the lowest temperature at which a line drawn 60° to the horizontal axis is tangent to the weight loss curve. This is an empirical method of picking a temperature at which definite sample degradation occurs that can be readily duplicated by any operator. Some materials held at this temperature will degrade completely while others degrade only partially. Curve inspection will usually indicate the thermal behavior to be expected.

The maximum rate decomposition temperature is taken at the inflexion of the weight loss curve and represents the point of most rapid degradation of the material.

Range of accelerated rate change is the temperature range in which the thermogram depicts a steeper slope than either the preceding or subsequent slope. First and second merely indicates the order of occurrence in the direction of increasing temperature. This phenomenon of slope increase indicates the start of acceleration of a reaction, while slope decrease indicates the finish or deceleration of the previous reaction.

Final weight loss is the temperature range in which final decomposition is completed. In most polymers, a carbonaceous residue is formed which will gradually burn off, leaving an ash if nonvolatile inorganics are present.

Chemical analyses were made of three of the samples with aid of mass spectrographic and gas chromatographic techniques. The result of these analyses are shown in Table 24.

To determine the relative acute toxicities of the different materials, a large bell jar apparatus was modified to serve as an animal chamber. Inside the bell jar was a small furnace for material decomposition, a fan for circulation and a wire-net

TABLE 23

TGA DECOMPOSITION TEMPERATURE, °F, 1/2 ATMOSPHERE PRESSURE

Sample Name	Initial Weight Loss	Empirical Decomposition Temp.	Maximum Decomposition	Range of Accelerated Rate Change		Final Weight Loss
				First	Second	
Acrylonitrile	390	630	800-850	630-700	750-1000	1000-1400
Alkyl Resin						
Laminar	260	610	550-700	610-800	900-1000	1000-1250
Cellulose Acetate	350	640	700-750	640-780	1000-1300	-----
Cellulose Acetate						
Butyrate	330	640	700-750	640-850	1000-1230	-----
Epon 828 Laminar	400	610	650-700	610-700	900-1100	1100-1200
*Kel-F 240	640	710	750-800	710-850	-----	-----
Melamine	450	610	700-750	610-800	1300-1400	-----
Methyl Methacrylate	250	620	700-750	620-800	-----	-----
Nylon FM2	220	820	900-950	820-1100	-----	1100-1300
Phenolic Resin	230	750	850-900	750-1000	1100-1400	1400-1500
Polyester Resin						
Laminar	340	640	700-750	640-800	-----	900-1050
Polyethylene	550	830	900-950	830-970	-----	-----
Polypropylene	400	610	700-750	610-820	-----	-----
Polystyrene	430	650	700-800	650-800	-----	800-950
Polyvinyl Butyral	170	720	800-850	720-950	1100-1250	-----
Polyvinyl Chloride	480	600	650-750	600-850	900-1400	-----
Silicone DC 916	260	850	950-1050	850-1100	-----	1100-1350
Silicone Resin						
DC 7141 Laminar	500	770	1000-1100	770-1280	-----	-----
*Teflon	850	910	1000-1050	910-1100	-----	-----
Butyl 325 (Gum Stock)	450	620	670-720	620-760	-----	760-900
Hypalon 20	340	550	870-920	550-750	800-950	950-1100
Natural Gum Rubber						
(Smoked Sheet)	390	640	700-750	640-0	-----	800-1130
Neoprene WRT (Gum Stock)	360	550	600-650	550-700	750-950	950-1400
Polyurethane Adiprene C	390	540	750-800	540-900	1100-1300	-----

*Teflon and Kel-F decomposed into materials that attacked the container and rendered accurate interpretation of the last portion of the analysis infeasible. However, if either material were heated at any temperature in the "Range of Maximum Decomposition", major degradation would be achieved.

TABLE 24

CHEMICAL ANALYSIS OF THERMAL DEGRADATION PRODUCTS

<u>Material</u>	<u>Products Detected By Mass Spectrograph</u>	<u>Products Detected By Gas Chromatograph</u>
Butyl Rubber	Carbon Dioxide Carbon Monoxide Ethane Propane	Carbon Dioxide Carbon Monoxide
Acrylonitrile	Carbon Dioxide Carbon Monoxide Ethane	Carbon Dioxide Carbon Monoxide Ethane Hydrogen
Neoprene	HCl	Carbon Dioxide

TABLE 25

RELATIVE TOXICITY

<u>Substance</u>	<u>LD₅₀ (mg/liter*)</u>
Elastomers:	
Acrylonitrile	19
Butyl Rubber 325, Gum Stock	38
Hypalon	66
Natural Gum Rubber, Smoked Sheet	11
Neoprene WRT, Gum Stock	10
Polyurethane Adiprene C	8
Silicone Rubber, DC 916	4
Plastics:	
α KEL-F 240	3
Nylon FM-2	52
Polyethylene	7
Polystyrene	80
Polypropylene	26
Polyvinyl Butyral	17

* Milligrams of material decomposed.

cage to house four mice. Accessory equipment included a pressure manometer, a Variac for furnace control, a paramagnetic oxygen gas analyzer, and a Hempel carbon dioxide analysis unit. A cold water cooling coil removed heat from the furnace wall preventing a temperature build-up within the chamber.

For toxicity determinations, a small weighed sample of material was placed in the furnace crucible, four mice were placed in the cage, and 10 grams of dessicant was spread out in a flat metal receptacle for humidity control. The apparatus was evacuated to 25,000 ft. and pure oxygen leaked in to bring the altitude down to 18,000 ft. This resulted in a partial pressure of 156 mm for oxygen, equivalent to sea level. Tests made with control animals indicated no pathological effects due to the altitude changes. A comparison of the relative toxicity of several materials is shown in Table 25. Since only four animals were used per trial, the statistical significance of the data is limited.

APPENDIX E

POLYMER IDENTIFICATION

Some of the polymers, such as Teflon, are homopolymers and, therefore, easily identifiable by specific chemical formulas. Others, such as epoxies or polyesters, are copolymers with other monomers or polymers thus making only generic chemical formula identification possible. Since most commercial polymers are either copolymers, or complex mixtures of copolymers, with solvents, plasticizers and fillers added to obtain the desired physical and chemical properties, their complete chemical formula identification cannot be made without direct information from the respective manufacturers.

1. Acrylics

Homopolymers of such acrylates as acrylic acid, $\text{CH}_2 = \text{CHOOH}$, methyl acrylate, $\text{CH}_2 = \text{CHCOOCH}_3$, methyl methacrylate, $\text{CH}_2 = \text{CCOOCH}_3$, ethyl acrylate, $\text{CH}_2 = \text{CHCOOC}_2\text{H}_5$, and acrylonitrile, $\text{CH}_2 = \text{CH-CN}$, or copolymers with other monomers, the most important of which are: vinyl chloride, vinyl acetate, vinylidene chloride, vinylpyridine, butadiene and styrene. Typical cast acrylic is methacrylate "Plexiglas" of Rohm & Haas, typical acrylic rubber is a copolymer of acrylonitrile with butadiene (and styrene) such as "Hycar" of Goodrich, or Goodyear's "Chemigum."

2. Alkyd Resins

Oil, modified polyesters (vide 13).

3. Cellulose Acetate

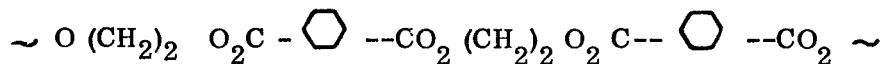
An ester of cellulose, obtained from natural sources such as cotton linters or chemical pulp, and acetic acid, CH_3COOH .

4. Cellulose Butyrate

Mixed ester of cellulose and acetic-butyric anhydrides.

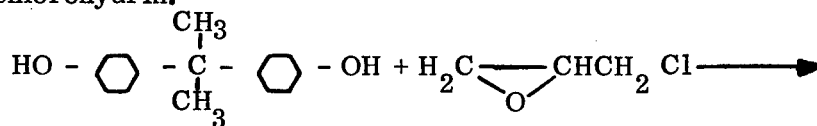
5. Dacron (DuPont)

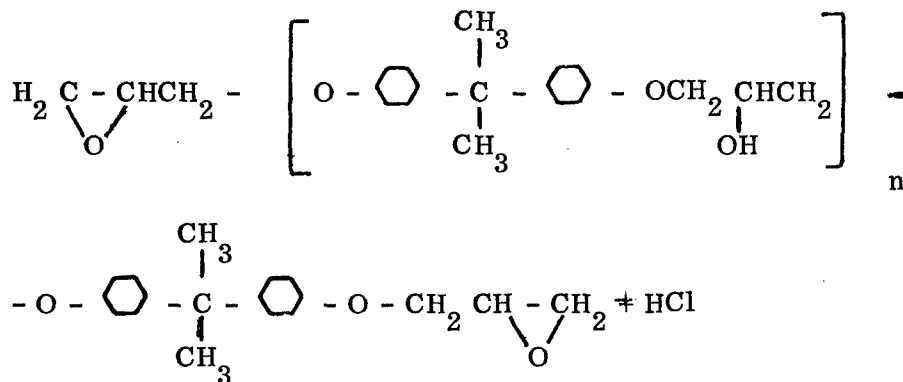
Poly (ethylene terephthalate) polyester fiber.



6. Epoxy Resins

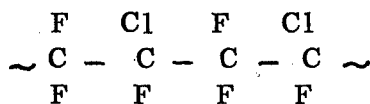
Resins which are derived from the epoxide group are $\text{CH} \xrightarrow{\text{O}} \text{CH}_2$. A typical example of an epoxy resin is the product of reaction between bisphenol A and epichlorohydrin.





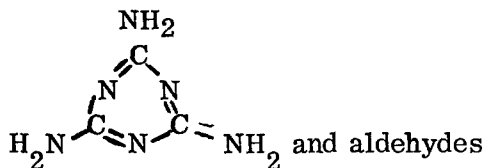
7. Kel-F

A polymer of chlorotrifluoroethylene, whose molecular structure is:



8. Melamine Polymers;

Polymers of melamine,



such as formaldehyde, CH_2O

9. Mylar (DuPont)

Poly (ethylene terephthalate) extruded film of the same chemical composition as Dacron.

10. Nylon

Any of the long chain polyamide polymers such as "nylon 66"



11. Orlon (DuPont)

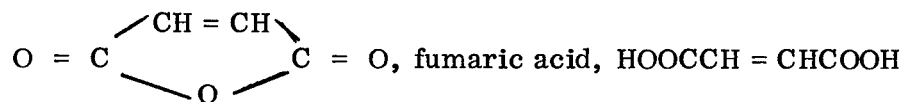
An orientable fiber made from polymers containing mostly acrylonitrile, $\text{CH}_2 = \text{CH} - \text{CN}$, in the chain.

12. Phenolic Polymers

Products of reaction between phenol, $\text{C}_6\text{H}_5 - \text{OH}$ and an aldehyde such as formaldehyde, CH_2O . The polymers are usually tridimensionally cross-linked.

13. Polyesters.

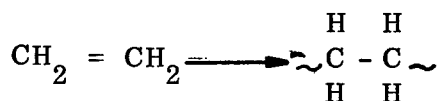
Unsaturated polyesters of such acids as maleic anhydride,



and polyhydroxyl alcohols such as ethylene glycol, $\text{HOCH}_2\text{CH}_2\text{OH}$, and propylene glycols, $\text{HOC}_3\text{H}_6\text{OH}$, cross-linked to thermosetting copolymers with vinyl monomers, usually styrene.

14. Polyethylene

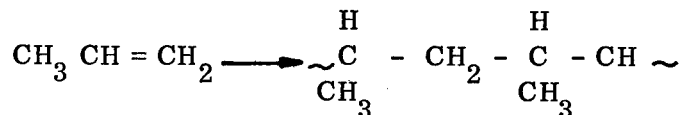
A polymer formed from ethylene



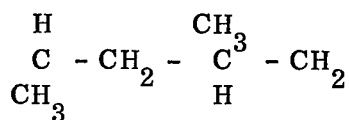
15. Polypropylene

A polymer formed from propylene.

(a) atactic form (Random)

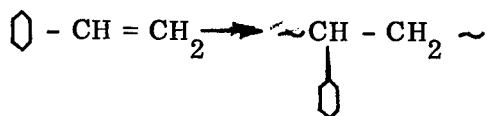


(b) syndiotactic form (stereospecific)

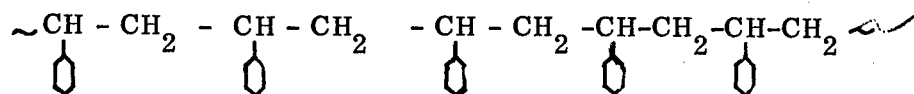


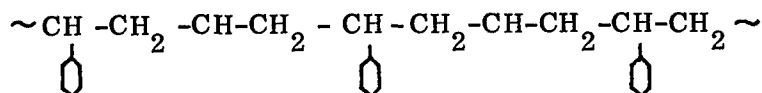
16. Polystyrene

A polymer of styrene



(a) Rexolite - Cross linked Styrene



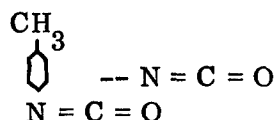


(b) Styrene Rubber Copolymers

Copolymers of styrene with natural rubber or such monomers as butadiene
 $\text{CH}_2 = \text{CH} - \text{CH} = \text{CH}_2$.

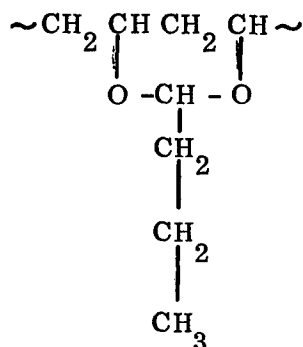
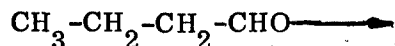
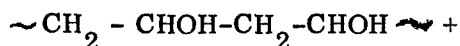
17. Polyurethanes

Products of reactions between polyhydroxy compounds and polyisocyanates. The iso-cyanate group, $-\text{N} - \text{C} = \text{O}$ is extremely reactive with active hydrogen. Polyurethane foams are made by reacting saturated polyesters, unsaturated dibasic acids, such as maleic acid, and di- and tri-isocyanates such as toluene 2,4-diisocyanate,



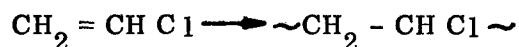
18. Polyvinyl Butyral

A copolymer of polyvinyl alcohol and butyraldehyde.



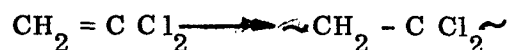
19. Polyvinyl Chloride

A polymer of vinyl chloride



20. Polyvinylidene Chloride

A polymer of 1,1-dichloroethylene

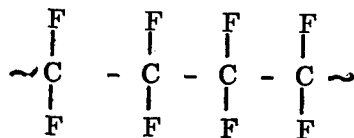


21. Silicone Polymers

Polymers in which some of the carbon atoms are replaced by the silicon atoms. Polymers are prepared from mono di, tri, and tetrahalosilanes of the type RaSi_aX_b , where $a + b = 4$.

22. Teflon

Polytetrafluoroethylene,



APPENDIX F

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OF HIGH MOLECULAR WEIGHT MATERIALS

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APPENDIX G

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